Quality Assurance Project Plan
Wigwam Bay Coastal Wetland Restoration Feasibility Study

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APPENDICES

Appendix A – Great Lakes Coastal Wetland Monitoring Program QAPP (CMU 2025)
Appendix B – USACE 1987 Manual
Appendix C – USACE Regional Supplement NCNE
Appendix D – USACE Drilling and Invasive Activities at Dams and Levees ER 1110-1-1807 (2023)
Appendix E – Sampling Strategies and Statistics Training Materials for Part 201 Cleanup (MDEQ 2002)
Appendix F – Sample Chain of Custody Form

1 QAPP Organization and Management

1.1 Distribution List

This Quality Assurance Project Plan (QAPP) will be distributed and implemented by all project partners listed in **Table 1**. The QAPP will also be placed in a field binder and made available to all field staff involved in the project. Digital files of the data and reports will be compiled and made available to people and organizations upon request.

Table 1. Contact Information for Key Personnel

Name	Responsibility	Address	Phone/e-mail
Kylie McElrath, Audubon Great Lakes	Grantee Contact, Project Manager,	200 W Madison St., Ste 300, Chicago, IL 60606	312-453-0230 (x2011) kylie.mcelrath@audubon.org
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Forrest Grenat, PS Rowe	QA Manager	2342 Industrial Street, Suite A Grayling, MI 49738	989-348-4036 fgrenat@rowepsc.com

1.2 Project/Task Organization

In addition to approving this document, the Audubon Great Lakes (AGL) and Great Lakes Fishery Commission (GLFC) QA Managers will oversee all aspects of this feasibility study including project data collection and analysis. The AGL and GLFC Project Manager and GEI Project Manager will oversee and supervise their respective parts of the project. Data collected for this project by Rowe Professional Services Company (Rowe), Job Site Services, Inc. (JSS), Grand Valley State University (GVSU), and GEI Consultants of Michigan, P.C. (GEI)

including but not limited to, wetland delineation, vegetation assessment, topographic and bathymetric surveys, geotechnical analysis, hydrologic monitoring, sediment sampling for contaminants, biological assessment, and water and sediment sampling for phosphorus is subject to review by the AGL Project Manager. Refer to section **3.2** (Data Review, Validation, & Verification) for further discussion.

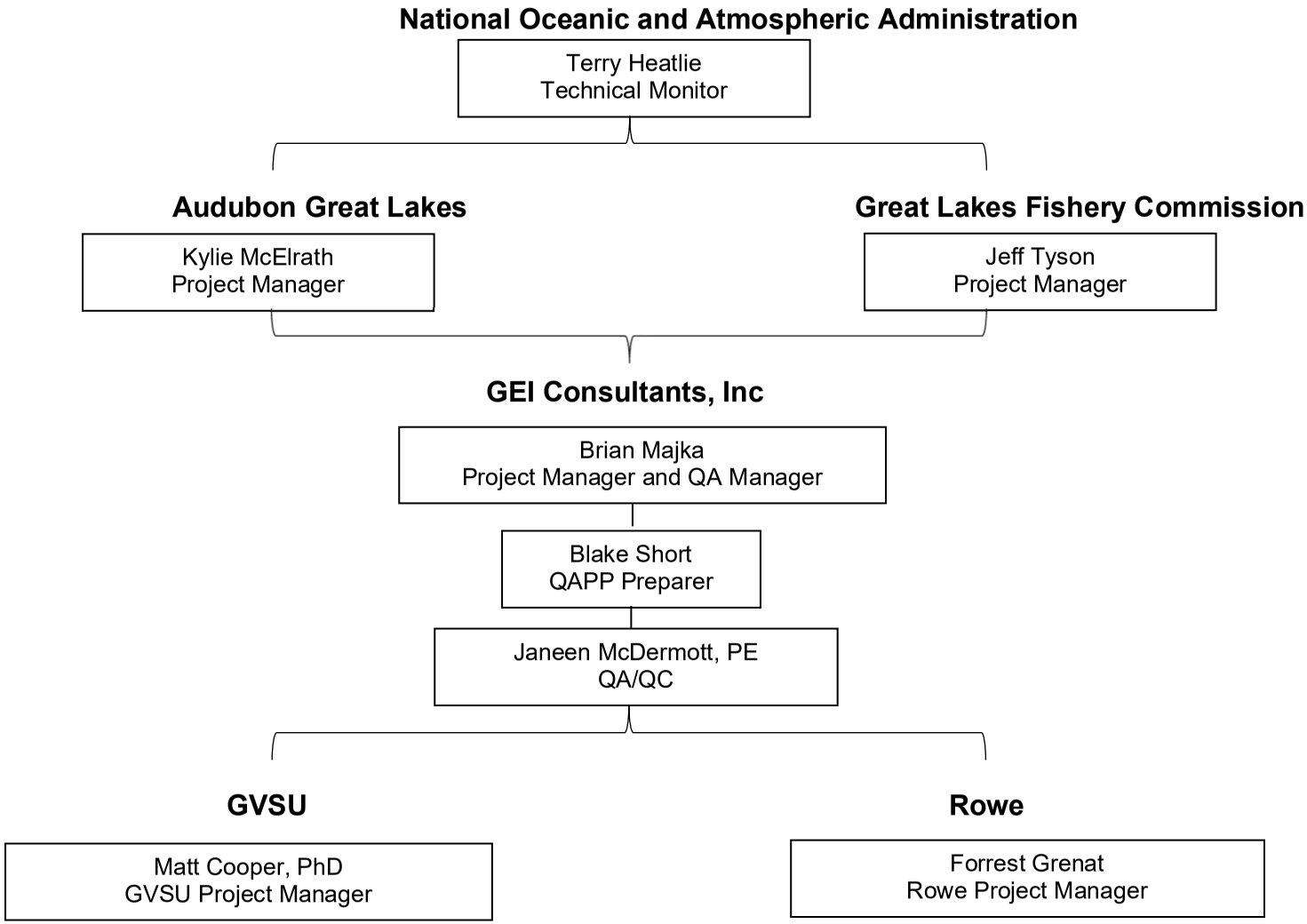
Please note that all work completed by GVSU is covered under an EPA-approved QAPP for the Great Lakes Coastal Wetland Monitoring Program (Appendix A). Therefore, all relevant criteria from the existing QAPP will be followed for the purposes of this project.

AGL will serve as the grant administrators for this project. GEI will lead the wetland delineation, vegetation surveys, geotechnical sampling, sediment sampling, and hydrologic monitoring. Rowe will complete the topographic and bathymetric surveys. GVSU will be responsible for water sampling and biological surveys. NOAA is providing funding, QAPP review, QA/AC, and technical input to the project. Roles of key personnel are provided in **Table 2**.

Table 2. Roles and Key Personnel

Name	Organization	Role
Kylie McElrath	Audubon Great Lakes	Grantee Contact, Project Manager
Terry Heatlie	NOAA	Technical Monitor
Jeff Tyson	GLFC	Project Manager
Blake Short	GEI Consultants of Michigan, P.C.	QAPP Preparer
Brian Majka	GEI Consultants of Michigan, P.C.	Project and QA Manager
Janeen McDermott, PE	GEI Consultants of Michigan, P.C.	GEI QA/QC
Matt Cooper	GVSU	QA Manager, Biological Surveys and Water Quality
Forrest Grenat	Rowe	QA Manager, Survey

Project # NA25NMFX463C0069-T1-01 **Organizational Chart**



1.3 Problem Definition/Background

Wigwam Bay State Wildlife Area (SWA) is a complex of Great Lakes coastal wetlands that lies at the northern shores of Saginaw Bay in Lake Huron. Wigwam Bay SWA is managed by the Michigan Department of Natural Resources (MDNR) and totals approximately 3,500 acres, of which 900 acres have been physically disconnected from the bay through a system of earthen embankments. The disconnection has interrupted the natural flow of water and sediments between Saginaw Bay, the Rifle River, and the wetlands. Additionally, in its current configuration, water level manipulation within the impounded wetland is limited to outflows through three sets of culverts with slide gates for water level control. Remnants of the historic Rifle River channel are still present and visible but no longer carry active flow.

The project location was historically part of a complex of Great Lakes marsh and shrub swamp, as well as the historic location of the confluence of the Rifle River and Saginaw Bay. From an ecological perspective, Great Lakes marshes provide critical habitat for breeding and migratory birds, fish, herpetofauna, mammals, mollusks, and insects that require clean water, native plants for nesting, spawning and foraging habitat, and connectivity to Lake Huron throughout their life cycle. Currently, Wigwam Bay SWA supports populations of Black Tern (*Chlidonias niger* – state threatened), Least Bittern (*Botaurus exilis* – state threatened), and Blanding's turtle (*Emydoidea blandingii* – state special concern). However, populations have declined from habitat loss, predation, and other threats.

The unique conditions at Wigwam Bay SWA present challenges when managing for birds, fish, anurans, and other wildlife. Rerouting of the Rifle River and historic anthropogenic disturbance (e.g. impoundments) on a landscape scale have severed connectivity to Saginaw Bay and the Rifle River, altered hydrology, disrupted natural processes influenced by the Great Lakes, and maintained static water levels which likely encourages the expansion of non-native cattails. Additionally, surveys in 2018 by the MDNR and 2020 by Environmental Consulting & Technology (ECT) showed the impounded wetlands maintain a water surface elevation that stays consistently between 0.5 to 5 feet above the elevation of Saginaw Bay, with muted water level fluctuations when compared to temporal fluctuations in the adjacent Lake Huron. This elevation difference between water levels in the marsh and the lake, likely indicates the presence of springs within the marsh. Water level fluctuation is a critical natural process of coastal wetlands and greatly influences vegetative zonation, current, nutrient content or availability, water temperature, and other factors.

AGL has partnered with MDNR and the GLFC to develop a feasibility study to assess existing conditions including current hydrologic and geotechnical conditions, barriers to fish passage, infrastructure modifications, nutrient dynamics, water level control, and habitat management to develop recommendations for wetland and habitat restoration. This project represents Phase I of a multi-phase restoration effort to enhance ecological function and resilience within the Wigwam Bay SWA. The feasibility study will provide the foundation for subsequent phases of the project including full engineering design, anticipated permitting considerations, and order-of-magnitude cost estimates for implementation of restorative measures. The overall project goal is to allow for seasonal (or other) movement of fish and other aquatic biota into and out of the wetland complex while restoring functional hemi-marsh and open-water conditions that benefit species such as the Black Tern, Least Bittern and other secretive marsh birds, and Blanding's turtle, and address nutrient and water quality impairments. Anticipated benefits of the project include:

- Water level management that allows flow of water through the wetland complex allowing pass-through of sediment and nutrients as well as increased dissolved oxygen levels;
- Hydrologic reconnection, either active or passive, to Saginaw Bay that can allow fish to enter the marsh while limiting common carp;
- Habitat improvements for anurans, including the potential for basking logs and reptile/amphibian hibernacula;
- Management of non-native cattail and restoration of plant communities such as Great Lakes marsh and hemi-marsh that can provide various habitat types for wildlife and will function at both high and low Lake Huron water levels
- Woody habitat structures, such as inverted root wads, to increase habitat complexity and create island-like habitat features that may reduce predator access for nesting birds and other marsh wildlife;
- Improve internal marsh conditions in the impoundment to promote the development of floating and emergent herbaceous vegetation that provides nesting substrate for breeding marsh birds such as the Black Tern.
- Water quality management to improve water quality in the impoundment and/or minimize impacts to Saginaw Bay, if needed based on water quality and sediment sampling.

1.4 Project Task/Description

The overall project will include the restoration of Great Lakes marsh and hemi-marsh conditions, enhancement of aquatic habitat, and potential connectivity to Saginaw Bay, functions that are vital to self-sustaining populations of breeding

and migratory birds, waterfowl, fish, reptiles, amphibians, and migratory birds within the diked Wigwam Bay SWA. In order to design the restoration and measure the impact of restoration efforts, monitoring and data collection will be conducted in the form of topographic and bathymetric surveys, hydrologic monitoring (surface water and groundwater levels and weather monitoring), wetland delineation, vegetation and biological surveys, and sediment and water sampling for phosphorus and contaminants. Analysis for remaining major tasks of the feasibility study following data collection and include fish passage, water level management, nutrient assessment, connectivity evaluation, identifying permitting requirements, and conceptual site design layouts.

Data collected for the proposed feasibility study include:

- Wetland delineation
- Vegetation and biological surveys
- Topographic and bathymetric surveys
- Hydrologic assessment, including surface water levels and weather monitoring
- Geotechnical assessment
- Water quality and sediment sampling

Success of the project tasks will be evaluated using NOAA Tier 1 monitoring metrics for fish hydrologic reconnection. Pre-restoration data will be collected for this effort, and post-restoration will be collected during future efforts. For reference, monitoring metrics and target goals are summarized below in **Table 3.**

Table 3. NOAA Tier 1 Monitoring Metric Summary

Monitoring Metric	Schedule	Measurements	Target
Land Elevations	Pre-construction	Topographic survey	Accurate topographic data
Water Levels	Pre-construction	Staff gauges, transducers	Indication of progress towards project goals.
Operating and maintenance (O&M) costs	Pre-construction	expected average annual O&M costs	Reduction or elimination of O&M costs

** Target will be refined following on-site surveys.*

Data collection methods are discussed in further detail in Section **2.1**.

1.4.2 Project Area

The project location is ±900 acres of emergent wetland and open water bisected by a ±2.1-mile remnant segment of the historic Rifle River channel. The re-routed river now flows into the adjacent marsh and towards Saginaw Bay via a matrix of ditches and swales. The project site is approximately 5.25 miles southwest of the city of Au Gres, Arenac County, Michigan. (Lat. 43.99468, Lon. -83.77000 (**Figure 1**)).



Figure 1. Location Map Wigwam Bay SWA (Nearmap 2023)

1.4.3 Schedule

Phase I, the Wigwam Bay Coastal Wetland Restoration Feasibility Study will take place during the latter half of 2026 through August, 2028. Project data collection will begin in 2026 and continue through the third quarter of 2027 (**Table 4**). Compilation and analysis of data will occur throughout much of 2027 and 2028 and will be used for development of restoration design plans, estimated costs, and permitting requirements for later phases of the project.

Table 4. Project Data Collection Schedule

	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	5th Quarter	6th Quarter
	Jul-Sept 2026	Oct-Dec 2026	Jan-Mar 2027	Apr-Jun 2027	Jul-Sept 2027	Oct-Dec 2027
QAPP Development and Review Period	X					
Wetland Delineation and Vegetation Assessment	X	X		X		
Topographic and Bathymetric Survey/Land Elevations		X	X	X		
Geotechnical Assessment	X	X	X	X		
Hydrologic Assessment Water Levels and Weather Monitoring	X	X	X	X	X	
Soil and Sediment Sampling	X	X				
Fish, Avian, Anuran, and Macroinvertebrate Surveys	X			X	X	
Water Quality Sampling	X	X				
Operating and Maintenance Costs			X	X	X	X

1.5 Training Requirements

Specialized training is required for some of the data quality objectives. Many of the sampling methods, protocols, and indicators have already been established in the EPA QAPP approved for the GLCWMP (Appendix A). By following these methods, representative and reproducible monitoring results can be generated. The primary data quality objectives for this program is the acquisition of accurate and representative measurements of the biological, habitat, and supplemental water quality parameters for all major Great Lakes coastal wetland complexes, collected in accordance with established Great Lakes CWMP methods. It is very

important that the data collected are representative of the condition of each wetland, are collected following GLCWMP protocols, and are collected similarly by all field crews across the Great Lakes.

1. All field staff performing wetland delineations are trained in the use of the USACE Wetland Delineation Manual (1987) and corresponding Northcentral and Northeast Regional Supplement, Version 2.0 (2012) (Appendix B and C). If delineations are not performed by a certified Professional Wetland Scientist (PWS) they will be reviewed by a PWS. Vegetation surveys will be performed by field staff with experience and knowledge of the regional flora and natural communities of southern Lower Michigan.

2. Topographic and bathymetric surveys will be completed by surveyors that hold a Michigan Professional Surveyor (PS) license.

3. Soil borings for the geotechnical assessment of the embankment soils will be completed by a subcontractor experienced with rotary drilling methods and collecting fully cased boreholes. A GEI geotechnical engineer will be on site when all borings are taken to record the soils data, according to the established policies and requirements outlined in USACE Engineer Regulation 1110-1-1807 for drilling and other invasive activities in/on/under all USACE dams or levees (Appendix D).

4. The hydrologic assessment will be completed by GEI ecologists or engineers experienced with hydrologic monitoring and ecological restoration. The water level gauges contain continuous-recording pressure transducers and recorded data are uploaded to the digital database by field staff that demonstrate competency in data transfer and collection. The weather station also continuously records temperature, wind speed and direction, precipitation, relative humidity and barometric pressure.

5. Soil and sediment samples for contaminant analysis will be collected by personnel with familiarity and experience collecting field samples using strategies outlined in the MDEQ (now EGLE) Sampling Strategies and Statistics Training Materials and chain of custody procedures (Appendix E and F). Samples will be analyzed by a lab with National Environmental Laboratory Accreditation Conference (NELAC) accreditation.

6. Biological surveys, which consist of passive fish sampling, macroinvertebrate sampling, and aural, visual and broadcast avian surveys, will be performed by trained biologists and ecologists following the GLCWMP protocols (Appendix A).

7. Water quality samples will be collected by personnel with familiarity and experience collecting field samples. Water quality will be sampled according to the established CWMP protocols (Appendix A). Water quality samples will

be measured in the field with handheld instruments and sediment samples will be analyzed by a lab with NELAC accreditation.

2 DATA COLLECTION & QUALITY STANDARDS

2.1 Field Data Collection Requirements

Data represented in **Table 5** will be collected to inform restoration design, meet NOAA Tier 1 monitoring requirements, and assess restoration efficacy. Each data type is further detailed within its respective section along with sampling frequency and duplicate number. Data is separated into 2 classifications: informational data and critical data. Informational data is used to inform the project team on existing site conditions for baseline information. Critical data will be collected to assess changes to the site through the restoration design process.

Table 5. Project Data Collection Summary

Data Type	Number of Samples	Number of Sampling Events	Data Classification
Wetland Delineation	1 survey of the ±900-acre site	1	Informational
Vegetation Survey	1 survey for floristic inventory and natural communities	1	Informational
Bathymetric Survey	1 survey of former Rifle River channel and relocated channel at 400’ increments; cross sections along Big Creek Drain, select bathymetry throughout the site	1	Critical
Topographic LiDAR Surveys/Land Elevations	1 Fixed Wing Aerial LiDAR Survey flight across entire site	1	Critical
Topographic Ground and Parcel Survey	1 survey to locate culverts, gates, buildings, water elevations, private land boundaries etc.	1	Critical
Geotechnical Assessment	20 soil borings along the embankment crests	1	Critical
Hydrologic Assessment/Water Levels/Weather Monitoring	4 groundwater piezometers and 2 surface water level gauges and 1 weather station continuously monitoring air temperature, wind direction and speed, precipitation, relative humidity and barometric pressure	1	Critical
Sediment Sampling for Phosphorus and Contaminants	1 location per hectare at surface (360 sample locations, 360 samples for P); 10 samples sent for contaminant analysis	1	Critical
Biological Surveys	3 locations for avian, fish, and macroinvertebrates	2	Informational

Data Type	Number of Samples	Number of Sampling Events	Data Classification
Water Quality Sampling	40 samples	1	Critical
Operations and Maintenance Costs	1	1	Informational

2.1.1 Wetland Delineation and Vegetation Assessment

GEI and Orbis wetland ecologists will perform on-site investigations to delineate wetlands according to criteria defined by the U.S. Army Corps of Engineers (USACE) 1987 Wetland Delineation Manual and the Regional Supplement to the Corps of Engineers Wetland Delineation Manual (Version 2.0): Northcentral and Northeast Regions (January 2012) (Appendix B and C) to assess the soils, hydrology, and vegetation at representative points along wetland/upland boundaries. This wetland delineation protocol is the method accepted by EGLE. GEI will not flag wetland boundaries but will locate wetland boundaries using Global Positioning System (GPS). GPS mapping will be conducted with the ArcGIS Collector application and a Trimble DA2 GNSS receiver to facilitate sub-meter accuracy and will be completed concurrently with the wetland delineations. Wetland Determination Data Forms will be filled out at representative locations to provide documentation of wetland/upland boundaries.

In addition to the wetland delineation, ecologists will map natural communities and record identified species and their abundance (e.g. dominant, common, uncommon, rare) within the impoundment. Vegetation surveys will be conducted utilizing meander survey methodology, both on-the-ground and from kayak, to identify plant communities, changes in ecological patterning, notable high-quality areas, abundance of invasive vegetation, and other unique ecological features. Plant species nomenclature will follow that of Michigan Flora (Voss, Reznicek 2012). Natural communities will be defined according to the Michigan Natural Features Inventory Natural Community Classification System.

2.1.2 Topographic and Bathymetric Survey

A topographic/bathymetric survey, topographic ground survey, and parcel survey of the impoundment at the Wigwam Bay SWA and immediate adjacent land will be performed by ROWE. Fixed Wing Aerial LiDAR Flight, topographic ground surveys, and bathymetric surveys along the historic Rifle River channel, relocated channel, and Big Creek Drain will be conducted to create a comprehensive base map of the impoundment and surrounding area. Due to the scale of the site and amount of time needed, surveys will be completed in both Fall 2026 and Spring 2027.

A Fixed Wing Aerial LiDAR Survey Flight will be conducted across the entire site in 2026. Data will be collected from an altitude of 4,520 feet at an average of 62 points per square meter with a vertical accuracy on hard surfaces of ±0.25 feet.

Due to the shallow water and soft bottom, ROWE will use a Single Beam Echo Sounder (SBES) to collect cross sections of the historic river channel through the project site and the relocated channel along the west berm every ±400 feet in 2026 and every ±100 feet in 2027. Additional cross sections will be collected 500 feet upstream of the north berm and 500 feet downstream of the east berm in 2026 and 2027. In the event that SBES data collection is not feasible due to site conditions, elevations will have to be collected manually. Each cross section will include the top of bank, inner berm (if applicable), bottom of bank, centerline of channel (thalweg), top of sediment, hard pan bottom and water surface. Two cross sections in 2026 and six cross sections in 2027 will be collected along Big Creek Drain at the northeast corner of the site.

A topographic field survey of the project site will be conducted to locate and verify all culverts, buildings, gates and other features, water level elevation observations, and site photos. Horizontal control points and vertical benchmarks will be collected at culvert areas A through G per 2018 MDNR survey for future construction staking. Critical manmade objects including the existing berm and water control structures will be located and shown on the drawings. Physical structures and utilities within the potential project area will be depicted on the survey drawings. Contours, at one-foot intervals, will be shown throughout the site. Field surveys will also be conducted to determine the west parcel boundary and south parcel boundary lines common to the adjacent privately owned parcels. ROWE will prepare and record PA132 Certified Survey of said boundary lines and record Land Corner Certificates as necessary.

The horizontal control will be established for the site utilizing MDOT Base-stations in conjunction with a Static network solution processed through NGS OPUS. The coordinate system will be Michigan State Plane (NAD1983) and Michigan Central Zone (2112). The OPUS derived vertical elevation will be verified to nearest recovered NGS monument to the site. A Trimble robotic total station or Trimble RTK GPS receivers will be utilized for any upland portions of the survey. The Trimble RTK GPS receivers will be connected to a Trimble GPS Base receiver over the OPUS control point for real time positioning.

The hydrographic survey data will be collected utilizing a Hydrolite SF200-9 single beam echosounder with a 200kHz frequency transducer mounted with an RTK GPS receiver providing high accuracy spatial positioning. Prior to

commencement of each hydrographic survey, the horizontal and vertical position will be verified with the site control.

Manual depth verifications will be conducted at the beginning and end of each day to verify depth observations. Latency should be very minimal due to the shallow nature of the area and the slower speeds of the survey. The data will be processed using Trimble Access and exported to AuotCAD to create the job specific bathymetric maps (plan view) and cross sections.

The invert elevations, dimensions, material type, road surface and general condition of all culvert/bridge crossings will also be recorded. In addition, critical manmade objects including the existing berm and water control structures will be located and shown on the drawings.

2.1.3 Geotechnical Assessment

Soil borings along the embankment crest will be taken by Job Site Services, Inc. (JSS). Twenty soil borings will be completed to a depth of 20 feet using wash rotary drilling methods and fully cased boreholes to prevent hydraulic fracturing of the embankment soils, which could destabilize the embankment, and to control borehole collapse which can compromise the quality of the soil sampling data. Split-spoon soil samples will be collected on 2.5-foot and 5-foot intervals to the completion depth of the boring. Standard test methods and practices of *Standard Penetration Test (SPT) and Split-barrel Sampling of Soils*, and *Thin-walled Tube Sampling of Soils for Geotechnical Purposes* will be followed (ASTM 2008).

A GEI engineer will be present during the drilling to oversee the drilling and sampling, prepare a drillers boring log, and take photos. Upon completion of the field work, soil samples collected will be sent to our geotechnical laboratory in Allendale, Michigan for index testing and classification. Exploratory borings will be used to inform a slope stability and seepage analysis. The embankment soil properties are unknown and therefore require a series of geotechnical soil borings to understand seepage paths and gradients and examine the stability of the embankment. If conditions are encountered that warrant additional testing, or if inspection results warrant additional borings, the GEI team will notify AGL prior to proceeding.

2.1.4 Hydrologic Assessment

The GEI team will install four groundwater piezometers and two surface water level monitoring gauges that contain continuous-recording pressure transducers.

The transducers will be suspended in the water column inside a small diameter stilling well, bolted to a metal post that is driven into the marsh bottom. One surface water transducer will be installed in the impounded area, and one will be

installed outside the impounded area. The posts will also have a staff gage bolted to the post so that water levels can also be read manually when project staff are on site. The groundwater piezometers (shallow groundwater wells) and transducers inside them will be installed in four locations at the north and north-adjacent limit of the site.

If a potential spring location can be identified within the impoundment itself (via signs of upwelling) we may install piezometers in that location to see if a spring flow rate can be determined.

GEI will also install one weather station that continuously monitors and records air temperature, wind speed and direction, precipitation, relative humidity and barometric pressure. Precipitation will be measured on site, and evapotranspiration will be estimated both using the temperature and relative humidity data measured on site and with data from the nearby Michigan State University Enviroweather station data from locations in and around Bay City and Port Elizabeth to monitor temperature, humidity and solar radiation. Potential Evapotranspiration will be used to estimate evapotranspiration from the marsh within the water balance model.

The water balance model (USEPA SWMM) will be calibrated both to the long-term water level, precipitation and evapotranspiration data and estimates of potential seepage and spring flow. In addition, a drawdown test in 2027 will be used to help estimate the potential inflow to the marsh from a spring or springs suspected to be contained by the embankments, The drawdown test will entail completely opening up the outfall culvert water control structures to drain out water in the marsh, then re-setting the water control structures to their original control elevations and then tracking how long it take for the marsh to re-fill to its former elevation.

Theoretically, data and estimates for all inflows and outflows except the spring flows will have been identified and the re-filling of the basin will inform the contribution and magnitude of spring inflows.

2.1.5 Sediment Sampling for Phosphorus and Contaminants

Nutrients, especially phosphorus, typically cycle between the sediment and water. Therefore, it is important to characterize phosphorus levels in both water and sediment. A sampling rate of one location per hectare (approximately one sample per 2.5 acres) is considered adequate to characterize nutrients on an agricultural site. The GEI team will gather 360 total samples (1 per 2.5 acres) throughout the site and sample for total phosphorus. The GEI team will use GIS to generate a

concentration map (heat map) of phosphorus concentrations to understand where they may be highest throughout the site.

Because the site is located within the Saginaw Bay Area of Concern, It is likely that any earth excavation associated with the project will require testing by the Department of Environment, Great Lakes, and Energy (EGLE) (WRD-048 Protocols) for potential contamination. This material will need to meet both landfill and EGLE standards for testing (Appendix C). The WRD-048 Protocols for sediment testing of dredge materials requires that six samples be taken for the first 10,000 cubic yards with one additional sample for every subsequent 10,000 cubic yards of dredge material. To provide a preliminary assessment at the site, 10 samples will be taken and analyzed for the following parameters:

- Polycyclic aromatic hydrocarbons
- Michigan 10 Metals (As, Cd, Cr, Cu, Pb, Hg, Ni, Seand Zn) – Method 6010
- Biochemical oxygen demand
- Total Polychlorinated biphenyls

Samples will be taken with bucket auger or hand vibracore at each location. During sampling, the recovered soil samples will be screened by a GEI team field scientist using an Organic Vapor Analyzer (OVA) equipped with a Photoionization Detector (PID) for the presence of volatile organic compounds. Soil samples will also be visually inspected for the presence of staining, discoloration, fill material, and noted for any odor. Samples will be collected for analysis from the intervals exhibiting the highest field screening levels. If contamination is not indicated (based on PID measurements, visual, or olfactory screening) a composite sample will be taken at each location.

All samples will be placed into laboratory-supplied sample containers with appropriate preservative. Chain of custody procedures will be initiated in the field at the time of sampling and accompany the samples to the laboratory. Chain of custody records will record the sample date, time, sample location, project information (name, number, etc.) sample designation, number of bottles, and requested analysis. The sampler will retain a copy of the record and forward the original with the samples to the analytical laboratory analysis. Samples will be submitted to a subcontract laboratory for analysis.

During the sampling event, the GEI team will record the location of the borings using a hand-held Trimble DA2 GNSS receiver, with sub-meter accuracy. Also, the characteristics of each sample will be described and noted. Soil samples will be examined by on-site GEI team staff at the time of drilling and described using

the Unified Soil Classification System (USCS) system. Color will be described using a Munsell Soil Color Chart.

2.1.6 Biological Surveys

Two rounds of biological surveys will be conducted, one in 2026 and one in 2027. Biological community surveys will be conducted at up to three habitat zones within the impounded area by trained biologists and ecologists following GLCWMP protocols and QAPP (Appendix A) The use of this protocol benefits the project as there are multiple CWMP sites outside the impounded area, allowing for direct comparison of biological communities documented inside and outside the impoundment.

Fish will be sampled using passive sampling equipment (fyke nets) set up in targeted locations and “fished” overnight. Nets will be checked to verify that air breathing animals (e.g. turtles) are released, if captured. Fish will be identified to species, counted, measured (minimum of 25 per species at age category), and released alive.

The macroinvertebrate community will be sampled using dip-nets that are swept through the water column from the sediment surface to the water surface. Invertebrates will be picked from the nets in the field and placed in leak-proof containers containing 95% ethanol, with the goal being to obtain at least 150 invertebrates per replicate sample.

Two rounds of avian point surveys will be conducted by trained staff with demonstrated proficiency in aural and visual identification of bird species. Surveys will include passive listening and broadcast intervals, the latter using broadcast equipment capable of broadcasting avian calls at an 80dB or greater level with minimal distortion and/or noise.

Two rounds of aural surveys will be conducted for anurans (calling frogs and toads) following the Great Lakes CWMP protocols. Anuran surveys will be conducted by trained staff with demonstrable proficiency in aural identification of anuran species.

Results of biological surveys will include but not be limited to:

- Taxa lists and counts for fish, macroinvertebrates, anurans, and birds, inclusive of native and non-native organisms observed.
- Representative photographs of field sampling activities and to the extent possible, fish, birds, and other wildlife observed during the surveys.
- Ancillary measurement/observations taken during surveys and field data sheets.

2.1.7 Water Sampling for Phosphorus

To compare the water quality within the Wigwam Bay SWA impounded area and adjacent areas, GEI team member GVSU will sample water quality utilizing water quality meters and methods according to the established QAPP-approved CWMP protocols (Appendix A). Water quality measurements using field instruments are made *in situ* using a Yellow Springs Instruments (YSI) 6600 or equivalent instrumentation.

The GEI team proposes to sample one surface water sample at 40 locations across the site where fish and macroinvertebrate surveys are conducted, as well as select other locations. Surface water samples will be analyzed for total phosphorus (TP), total nitrogen (TN), soluble reactive phosphorus (SRP), ammonia (NH4), nitrate (NO3), turbidity, and dissolved oxygen (DO), which are standard parameters analyzed for in the CWMP.

All water samples collected for chemical analysis will be collected with poly bottles (one for lab submission and one duplicate) and frozen as soon as possible and sent to a qualified lab for analysis. Sample numbers and numbers of sample bottles are noted on field data sheets. Chain of custody procedures will follow those described in the CWMP protocols (Appendix A). Samples remain in the custody of field crews until they are delivered to the designated water quality laboratory either in person or via courier service. A chain-of-custody form accompanies samples with a copy remaining with the field crew or regional laboratory, whichever initiates the shipment (Appendix F). At the laboratory, all sample codes are logged along with the date received and notes regarding sample condition.

2.1.8 Operating and Maintenance Costs

Operating and maintenance costs will be calculated pre- construction. Vegetation management and assessments for stability are expected to be the primary operating and maintenance costs associated with this project.

2.1.9 Public Safety

Due to the nature of this project, Public Safety will not be monitored.

2.1.10 Community Enhancement

Due to the nature of this project, Community Enhancement will not be monitored.

2.2 Quality Objectives & Criteria for Measurement Data

Quality Assurance/Quality Control (QA/QC) guidelines and rules have been established to ensure the reliability and validity of sample collection activities. Compliance with QA/QC is monitored by the QA Manager. The objectives are to:

- Ensure all procedures are documented, including any changes in administrative and/or technical procedures
- Ensure all field procedures are conducted according to sound scientific principles and have been validated
- Ensure all equipment is clean and properly functioning
- Monitor performance of the sample collection procedures by a systematic inspection program and provide for corrective action if necessary; and
- Ensure all data are properly recorded and archived.

Internal quality control procedures will be conducted by field and laboratory audits and the analysis of duplicate samples.

2.2.1 Project Objectives and Limits

Project data will be collected through wetland delineation and vegetative assessment, topographic and bathymetric surveys, geotechnical assessment, hydraulic assessment, sediment sampling for contaminants, biological assessment, sediment and water sampling for phosphorus. Observations in this project will meet the quality assurance objectives outlined in this section. Bias, accuracy, precision, completeness, representativeness, comparability, and detection limits will be used to assess data quality.

2.2.2 Bias

Bias is any conscious or unconscious deviation from the truth that may result in inaccurate data. Data collection will be completed by GEI, ROWE, and GVSU, and and potential sources of bias are summarized in **Table 6**.

Table 6. Potential Project Bias

Bias Category	Potential Sources of Bias	Best Practices
Sampling	Location - sediment samples, water quality samples	All sampling locations will be randomly selected or spaced equally along transects.
	Timing – wetland delineation, biological and vegetation assessments	All surveys will be conducted during the appropriate seasonal timeframes (section **1.4.3**)
	Sample size - wetland delineation, biological and vegetation assessments	Follow protocols to obtain representative samples (section **2.1**)
Observational	Data collection - all qualitative surveys	Alternate staff in different data collection roles
Equipment	Instrument error - all quantitative surveys	Calibrate equipment prior to use of equipment and follow minimum accuracy guidelines (section **2.3**), use the same equipment to the greatest extent possible

Bias in data collection will be minimized by strictly following methods established in protocols and by measures described in the QAPP.

2.2.3 Accuracy

Accuracy refers to how close a measurement is to the true or accepted value. Data collection for topographic and bathymetric surveys, wetland delineation studies, sediment and water quality sampling will be completed by qualified field personnel who will review and verify all recorded data. The process of peer review will ensure accurate observations and minimize human error or bias in reporting. Additionally, the QA manager will provide supplemental review of field observations.

A latency test will be run at the beginning and end of each survey to calculate any differences in position and depth. This should be very minimal due to the shallow nature of the area and the slower speeds of the survey. The data will be processed using Trimble Access and exported to AutoCAD to create the job specific bathymetric maps (plan view) and cross sections.

A constrained least squares adjustment of the site survey control will be performed using Trimble Business Center. Statistical analysis will be performed

to verify site control passes Chi Square test at the 95% confidence interval and a histogram of the Standardized Residuals. Subsequent topographic mapping will be verified to the adjusted site control at the beginning and end of each day.

Sediment and water samples for Phosphorus will be analyzed by GVSU following CWMP protocols. Sediment samples for contaminants will be analyzed by a commercial, accredited laboratory.

2.2.4 Precision

Precision is the degree of agreement between two or more measurements. Duplicate samples will be used to determine precision for environmental conditions. The relative percent difference (RPD) for each pair of duplicate measurements will be calculated as follows:

$$\text{RPD} = (C_s - C_d)/[0.5\times(C_s + C_d)] \times 100,$$

where C_s is the measured variable of the sample (e.g., water temperature), and C_d is the duplicate measurement of the same variable. Duplicates will be measured for each sampling reach. Data quality objectives are given in Table 7.

2.2.5 Completeness

Following a QA review of all collected and analyzed data, data completeness will be assessed by dividing the number of measurements judged valid by the number of total measurements performed. The data quality objective for completeness for each sampling event is 90%. If the program does not meet this standard, Project QA Managers will consult to determine the main causes of data invalidation and develop a course of action to improve the completeness of future sampling events.

2.2.6 Representativeness

Representativeness is the degree to which data accurately and precisely represent a characteristic of a population, variation at a sampling point, or an environmental condition. The proper design of the sampling program and adherence to sampling protocols ensure representativeness. Representativeness of field observations will be satisfied by following the QAPP design and using proper sampling techniques. Field duplicates also will assist in determining representativeness.

2.2.7 Comparability

Comparability is a measure of the confidence with which one set of observations can be compared with another. This is important for comparing between sampling locations and comparing data over time. To ensure data comparability,

GEI and GVSU will follow the same sample collection methods and use the same units of reporting. Every effort will be made to collect data under similar seasonal conditions in order to observe similar characteristics in fish, anurans, birds, invertebrates, wetlands, and water quality.

Table 7. Qualitative Data Quality Objectives Summary

Parameter	Precision (RPD)*	Accuracy	Completeness
Topographic Survey/Land Elevations	Within 2 standard deviations of mean	±0.25 ft.	90%
Wetland Delineation	n/a	95% correctly identified plants	90%
Hydrology/Water Levels	n/a	"number" of days recording	90%
Biological Assessment	n/a	95% correctly identified species	90%
Sediment/Water Sampling	n/a	n/a	90%

*EPA QAPP guidance provides that a max RPD of 20 may be appropriate for sampling

2.3 Instrument/Equipment Testing, Inspection, Calibration, & Maintenance

All equipment will be inspected, calibrated, and tested each day prior to use in the field. Field equipment will be maintained according to manufacturer's specifications and steps will be taken to fix any problems that are noted. If any equipment is beyond repair, replacement equipment will be used. Spare batteries for all equipment are to be available if needed. All maintenance procedures will be documented in the equipment maintenance logs or the field notebook. Repair and calibration records will be filed. Preventative maintenance and calibration procedures will be followed according to the manufacturer's specifications. Laboratory instruments will be routinely inspected by the laboratory staff to minimize the event of instrument failure.

While the equipment is not in use, it will be stored at the office of GEI or the corresponding subcontractor. Equipment used for sample collection will be cleaned and maintained with methods that align with the proper field practices. Any sampling equipment that may potentially be exposed to soil, air, or water contaminants will be rinsed and dried in a well-ventilated area to limit cross contamination between sampling sites. QA Managers will also communicate these requirements to any subcontractors that are involved in data acquisition so they follow the same protocol.

All instruments, cameras, GPS Units, projectors, and computers are visually inspected upon return from the field. Equipment is accounted for after use and

clean and functional before use. Logs are maintained accounting for all equipment use in the field.

All GPS data will be collected using a Trimble DA2 GNSS receiver with sub-meter accuracy, or equivalent. The GPS receiver will be set to capture data provided that at least 4 satellites are in view and the Position Dilution of Precision (PDOP) value remains at 6 or below. The receiver will use additional satellites as available. GPS units will be set to the NAD 83 coordinate system prior to use and manufacturer default settings will be employed for most other settings. GPS Accuracy will be checked against known map coordinates from control points or locations with known coordinates. Waypoint data will be post-processed and exported to ArcMap where surveyed and known control points will be compared. Waypoints with a standard deviation greater than 3 meters will be a basis for exclusion from acceptance. Differential correction will be used when available. Batteries will be checked for power prior to use. All accuracy tests will be recorded in a log (identifying the specific GPS receiver used) and maintained in the project file.

2.4 Analytical Methods Requirements

2.4.1 Wetland Delineation and Vegetation Assessment

Shapefiles will be created from the GPS data collected in the field and used along with existing aerial imagery (basemap) to create a site map detailing delineated wetland boundaries. All geospatial data sources in the map will be appropriately cited and data will be collected with sub-meter accuracy eliminating the need for any postprocessing of GPS data.

Data collected from wetland delineation field forms will be entered into the USACE Northcentral/Northeast Region Automated Wetland Determination Form (https://usace.contentdm.oclc.org/utils/getfile/collection/p16021coll9/id/3030). This data will then be summarized and included as attachments along with site figures in a wetland delineation report. Vegetation surveys will be conducted between June and early-October. Data collected from the surveys will include both species and estimated coverage so comparisons between pre- and post-restoration vegetation cover can be made. This data will be summarized and included as attachments along with the wetland delineation report.

The report will be reviewed by the QA manager for errors in data translation, discrepancies in known habitat features and control points on the site, and omissions of portions of the project area based on the final wetland delineation figures. The QA Manager will notify field personnel responsible for wetland delineation and create a plan to reconcile all identified errors.

2.4.2 Topographic and Bathymetric Survey/Land Elevations

The raw survey data will be processed and imported for analysis and final adjustment. In the process of adjusting, any outliers will be removed from the data set and not used in the final adjustment. All survey information will be provided to GEI in PDF and electronic formation (AutoCAD) for use in project modeling and design.

2.4.3 Geotechnical Assessment

The exploratory borings will be used to inform slope stability and seepage analyses. Seepage will be a component of the hydrologic assessment and water level management analysis. Data sheets will be reviewed by the QA manager for completeness and accuracy for each of the sampling locations. The QA manager will notify JSS field personnel responsible for geotechnical assessment and create a plan to reconcile all identified errors.

2.4.4 Hydrologic Assessment/Water Levels

The information gathered on-site via groundwater piezometers, surface water level monitoring gauges, and weather station, as well as the NOAA Saginaw Bay gauge and other local data sources (refer to **section 2.1.4**) will be used in combination with a drawdown test and the USEPA SWMM software to develop a water balance model to assess inflows and outflows, and to test various water level control scenarios in the model and build confidence in model results for projected scenarios. The ground and surface water level monitoring gauges contain continuous-recording pressure transducers that will collect data to be transferred to the electronic database. The weather station also measures and collects continuously monitored weather data that will also be transferred to the electronic database. The project QA Manager will review database entries and check for potential errors, signs of equipment malfunction, or incomplete data collection.

2.4.5 Sediment Assessment for Phosphorus and Contaminants

Sediment samples will be submitted to a commercial laboratory for analysis. Samples of the material proposed for excavation and removal from the sites will be collected to determine regulatory restrictions for reuse or placement and characteristics for landfill acceptance. During sample collection, the characteristics of the sampled material will be noted and described. All samples will be placed into laboratory-supplied sample containers with appropriate preservative. Chain of custody procedures will be initiated in the field at the time of sampling and accompany the samples to the laboratory. Samples will be submitted to a certified laboratory for analysis and analyzed for polycyclic aromatic hydrocarbons, TCLP of the MI ten Metals list, biochemical oxygen demand, and total polychlorinated biphenyls.

2.4.6 Biological Surveys

Biological surveys, including fish, birds, anurans, and invertebrates will be conducted during their respective active periods in 2026 and 2027. Data collected from the surveys will provide baseline biological community data to inform long-term biological survey plans and help identify species that may benefit from enhanced hydrologic connectivity and habitat restoration within the Wigwam Bay SWA impounded area. Further, these data can be compared with nearby CWMP sites to infer how current conditions limit or benefit specific species, as well as inform conceptual restoration scenarios and design alternatives that meet the restoration goals of the project.

Fish survey data will include species, number observed on site, and size comparisons. Macroinvertebrate surveys include both identification and count per sample area. Avian surveys include point counts; species identified visually or heard will be recorded.

The project QA Manager will review database entries and compare them to field survey datasheets for accuracy. Any error in database entry will result in the QA Manager contacting the field team lead and requesting revision to the entered data to reconcile the error.

2.4.7 Water Sampling for Phosphorus

Water samples will be analyzed on-site by GVSU and analyzed by the GVSU laboratory. During sample collection, the characteristics of the sampled material will be noted and described. All samples will be placed into laboratory-supplied sample containers. Chain of custody procedures will be initiated in the field at the time of sampling and accompany the samples to the laboratory. Samples will be submitted to a certified laboratory for analysis and analyzed for total phosphorus (TP), total nitrogen (TN), soluble reactive phosphorus (SRP), ammonia (NH4), nitrate (NO3), turbidity, dissolved oxygen (DO).

2.4.8 Operating and Maintenance Costs

GEI will use site information collected to determine operating and maintenance costs. Minor actions that can be dealt with without significant planning are scheduled and addressed through the normal workflow amongst other work priorities. More significant work that rises to the level of requiring detailed plans and permits are handled more like a project as these require more significant resource scheduling. These actions are addressed through a routine maintenance budget.

2.4.9 Public Safety

Due to the nature of this project, Public Safety will not be monitored.

2.4.10 Community Enhancement

Due to the nature of this project, Community Enhancement will not be monitored.

2.4.10 Non-direct Measurements

The Project Managers and QA Managers will notify potential non-measurement sources of project location and request existing environmental data that may be pertinent to better understand the effect of project implementation and measuring these changes. Relevant resource organizations include Grand Valley State University, Arenac County, EGLE, Michigan Natural Features Inventory, and the Michigan Department of Natural Resources. In the event that data is collected from these agencies, the Project Managers and the QA Managers will discuss their acceptance criteria and assess any limitations in adding this data to the project plan.

3 DATA MANAGEMENT & REPORTING

3.1 Data Handling/Storage

The AGL Project Manager and QA Manager will be responsible for distributing the QAPP to personnel on the distribution list. Copies will be submitted with a signature page to be returned to the Project Manager.

Documents generated by field activities, including field data sheets and notes, will be maintained in the project files. AGL, GLFC, and GEI will maintain a file of raw data, instrument printouts, preparation and run logs, calibration information, analytical data, quality assurance data, and chain of custody forms. An electronic summary of all data will be prepared.

AGL GLFC will maintain custody of data collected during the project. Data collected by GEI, ROWE, JSS, or GVSU, as required for project implementation, will be maintained by those respective organizations and provided to AGL. Field notes, data sheets, survey forms, permits, photos, and pertinent project documents will be stored in hard copy and electronic format by AGL, GLFC, GEI, ROWE, and GVSU. Upon completion of the project AGL and GLFC will receive custody of all data generated. Refer to data management plan, **section 3.1.2**, for details regarding record management.

ROWE, JSS, GVSU, and GEI will use standardized data sheets for data collection in the field. The QA Manager for each respective organization will be responsible for field data management standards during the project. The AGL

and GLFC Project Manager/QA Manager will review all data for accuracy and completeness.

Survey data collected in the field will be post processed in the office for development of appropriate map products and stored in the office.
All geo-referencing, observational data, photographs, and/or other data generated or collected for this project will be documented and archived in its original format. These and other datasets, as needed, will be compiled as Microsoft Excel spreadsheets, ArcMap attribute tables, scanned hard copy forms, and GIS files stored on a secure network. Consistent applications will be utilized for modeling and GIS database creation. Original data will be protected from manipulation and copies will be provided for further use, manipulation, and analysis. AGL will be responsible for archived data.

Individuals listed below will make assessments and implement actions throughout the course of the project.

Table 8. Assessment and Oversight Summary

Assessment Type	Staff	Results	Corrective Action
Objective	Project Manager	Completeness	Redo or Amend
Equipment Tests	Field Staff or Subcontractor	Pass / Fail	Repair or Replace
Data Completeness	Project Manager	Sampled vs Planned	Revisit or Amend
Data Quality	Field Staff or Subcontractor	Meets Quality Objective or Not	Questioned Data Points Excluded
Performance Criteria	Field Staff or Subcontractor	Meets / Not Meets Criteria	Questioned Data Points Excluded

Management Assessment and Oversight

Staff assigned to each assessment type will assess, record, and implement corrective actions as needed throughout the course of the project. Records will be kept detailing each assessment, the results, and any corrective actions needed. Field training assessments for pertinent project components will be conducted by certified professionals if support staff is utilized. All aspects of the ROWE, GVSU, JSS, and GEI collection process will be reviewed.

Data Management Plan

The project will generate environmental data and information, including data on vegetation communities, topography and bathymetry, soil characteristics, hydrology, sediment contamination, biological communities, and water quality. Datasets will include delineated wetlands, plant communities, topographic and

bathymetric elevations, hydrologic regime, geotechnical analysis, sediment contaminants, biological communities, water and sediment phosphorus concentrations at regular spacing and depths. Data will be collected by GEI, ROWE, JSS, and GVSU according to the methodologies and procedures outlined throughout **Section 2.** Data collected will be considered public domain and will be available, free of charge, immediately following processing and according to NOAA guidelines, at the website of AGL and/or GLFC. Archived records are kept for a minimum of 3 years and a maximum of 7 years following the completion date of the contract. Hard copy records are also stored for a minimum of three years and a maximum of 7 years. Archived data may be kept beyond 7 years at the discretion of AGL and GLFC if mutually agreed upon with NOAA. Data will include topographic/bathymetric surveys, wetland delineation data, vegetation and wildlife survey data, water quality analysis, sediment analysis, geotechnical boring data, hydrological data, and operations/maintenance cost data that are collected for the project. The data disseminated will include the following disclaimer:

Disclaimer: These data and related items of information have not been formally disseminated by NOAA, and do not represent any agency determination, view, or policy.

3.2 Data Review, Validation, & Verification

Upon review of data collected during the course of this project, the Project Manager may request clarifications or corrections as deemed necessary to achieve project goals.

Once collected in the field, all data will be cross reviewed by the AGL, GLFC and project QA managers for completeness and accuracy, and to ensure consistency with collection protocols. Data transfer will take place in the office into a computer and post processed into a Microsoft Excel Spreadsheet and ArcMap if applicable. Data that is collected by a subcontractor will be submitted to both the AGL and project QA managers for review. Data reports will be reviewed independently by each QA Manager to determine data quality and validation. If either QA Manager deems that the data is not of sufficient quality, it will be rejected until revisions are made.

All data produced by this project must be reviewed to evaluate the data against the method/procedural requirements (verification) and to determine whether the data meet the data quality objectives (validation). The review process involves:

- preliminary review of the data collected in the field

- secondary review of field records to verify data against method and SOP requirements
- review of the verified data by the respective QA manager for reasonableness
- validation by an objective third party if necessary; and
- assessment of the data for its usability to meet project goals.

3.3 Validation and Verification Methods

Verification of data completeness will be made after each data collection or monitoring event. Total known data collection events to date will be compared to total required data collection events to date. If the quantity of known and required events is not equal, the QA Manager will review all data entered into the electronic database until omissions are identified. Once the omission is identified, the QA Manager will discuss the omission with those responsible for collecting the field data and enter the collected information into the electronic database in a timely manner.

Validation will be made by viewing field data on the computer. Survey data points (waypoints) and GPS control points will be overlaid on aerial photos and compared for accuracy. All data collected will be cross referenced with photographs and field notes for accuracy and then reviewed by the QA managers.

Data verification focuses on QAPP compliance, while data validation considers technical reliability relative to decision-making and meeting project objectives. As a result, data verification is conducted before data validation.

The data verification process begins after data have been collected. Verification is an objective, mechanical process of checking individual data points against the QAPP specifications. There are four main elements of the verification process:

1. Compliance: An evaluation of whether SOP and QAPP requirements were followed, achieved, and/or completed successfully. Data must also have been recorded under conditions that met requirements. Compliance ensures that data pass numerical quality control tests, including accuracy and precision.
2. Correctness: A determination of whether data collection plans and protocols have been followed. Basic operations and calculations must also have been performed using properly documented and properly-applied algorithms.
3. Comparability: A measure of the extent to which data collection procedures were done in a similar manner across different sites and data

reporting was done in a similar manner. Comparability ensures that reported values are the same when used throughout the project.

4. Completeness: A measure of the extent to which necessary data were collected. Completeness ensures that a sufficient amount of data and information are present relative to the data quality objectives.

Data validation focuses on the ability to use data as intended to make decisions and to address project objectives. These qualifications address overall usability, not contractual adherence. The assigned qualifications for each datum will be usable (i.e., observation appears valid) or unusable (e.g., observation outside the valid range).

3.4 Reconciliation with User Requirements

Results and products will be evaluated against the Data Quality Objectives and user requirements to determine if any reconciliation is needed. Reconciliation concerning quality, quantity, or usability of the data will be reconciled with the user during the data acceptance process. Types of reconciliation may include reduction in the scope of the project in terms of quality or quantity of data produced to meet partial user requirements.

3.1 Documentation & Records

This project will involve an iterative process with open communication between GEI, AGL, GLFC, ROWE, JSS, GVSU, and NOAA. Discussions will address quality assurance issues as needed and may include limitations and constraints in the information sources and / or assumptions made about the information.

Deliverables to be submitted with quality assurance information include:

- Draft QAPP for approval and Final QAPP when approved
- GIS Maps, photographs, and field data forms
- GIS data (including metadata)
- Progress Reports - Status Updates
- Final Report - Project Summary upon completion

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Appendix A – Great Lakes CWMP QAPP

Appendix B – USACE 1987 Wetland Delineation Manual

Appendix C – USACE Supplement NENC

Appendix D – USACE ER 1110-1-1807

Appendix E – Sampling Strategies and Statistics Training Materials for Part 201 Cleanup (MDEQ 2002)

Appendix F – Sample Chain of Custody Form

Appendix A – Great Lakes CWMP QAPP

Quality Assurance Project Plan

Continuation of the Great Lakes Coastal Wetland Monitoring Program (GLCWMP): 2021-2025

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A3. Distribution List

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A4. Program Organization

This monitoring program is carried out by many individuals from many organizations located around the Great Lakes basin. Nearly all of the original authors of the GLCWC monitoring plan (GLCWC 2008), including many who contributed to indicator development, and many of the lead scientists from the Great Lakes Environmental Indicators (GLEI) project, are co-principal investigators (co-PIs). The program team (Figure 1) consists of U.S. scientists from Central Michigan University (Donald Uzarski, principal investigator/lead grantee; Matt Cooper, assistant QA manager/program coordinator; Thomas Gehring, Dennis Albert), the Natural Resources Research Institute (NRRI) at the University of Minnesota Duluth (Valerie Brady, program coordinator and QA manager, regional team lead), the Annis Water Resources Institute (AWRI) at Grand Valley State University (Carl Ruetz), the University of Notre Dame (Gary Lamberti), Lake Superior State University (Ashley Moerke), State University of New York-Brockport (Kathryn Amatangelo, regional team lead); and the University of Wisconsin (Robert Howe at Green Bay, Nick Danz at Superior, and Joseph Gathman at River Falls), and two resource management officials: Anne Garwood (Michigan Department of Environment, Great Lakes, and Energy) and Kurt Kowalski (USGS). Canadian scientists from the University of Windsor (Jan Ciborowski, regional team lead), Environment and Climate Change Canada (Giuseppe Fiorino), and Birds Canada (Doug Tozer) are also key participants.

Program coordination and QA management are provided by Don Uzarski (CMU), Valerie Brady (NRRI), and Matthew Cooper (CMU). These individuals ensure both cost-effective sampling and program oversight, and are responsible for all reporting to EPA. They are also responsible for assuring that all teams and participants are properly trained in QA/QC methods and procedures, and assist with QC evaluations throughout the program. They schedule regular meetings (once per year face-to-face) and conference calls/webinars among co-PIs to ensure coordination and foster communication among teams. Regional team leaders oversee QA/QC of their field teams, ensuring that field crew chiefs understand the importance of QA/QC and understand all methods and procedures. Field crew chiefs enforce QA/QC with their crews, checking that all crew members can follow all QA methods and pass QC checks on all aspects of their work.

Program Team Background and Qualifications
Dr. Don Uzarski (CMU) leads the entire GLCWMP effort. He was a member of the Project Management Team and Chair of the Science Committee that developed what has become the Great Lakes Coastal Wetland Consortium Monitoring Program (GLCWC 2008). As part of the Great Lakes Coastal Wetland Consortium, Dr. Uzarski's responsibilities included the development of: 1) a stratified-random statistical sampling design; 2) water quality and habitat protocols; and 3) fish and macroinvertebrate sampling protocols and indicators. He was also co-editor of the GLCWC final report and training manuals. Dr. Uzarski has worked on Great Lakes coastal wetlands since 1997. He has published more than 75 papers on coastal wetlands in peer-reviewed journals, conference proceedings, and book chapters.

Dr. Valerie Brady (NRRI) was the project coordinator for both of the Great Lakes Environmental Indicators (GLEI) projects, which worked on development of condition indicators for Great Lakes coastal wetlands, bays, and high energy coastlines. In addition to coordinating the 28 Co-PIs for the GLEI I and II projects, she also assisted with the macroinvertebrate and fish sampling effort and worked on developing macroinvertebrate indicators of wetland condition. She helped organize GLEI project fish and invertebrate field crew training and oversaw QA/QC. She assisted with database development for the entire GLEI project and helped Co-PIs determine how best to QC their data. She and Dr. Terry Brown (NRRI) completed a separate data transfer project for US EPA, including methods for assuring that metadata stay associated with datasets after data upload. Dr. Brady received QA/QC training as a post-doctoral associate at the US EPA Mid-Continent Ecology Division between 1997 and 2000. She subsequently worked on QA/QC for the Estuarine and Great Lakes (EaGLe) Coastal Indicators Initiative (funded by US EPA STAR), and has attended all of the QA/QC webinars offered by US EPA GLNPO. Brady has worked on Great Lakes coastal wetlands since 1989, publishing papers on this topic in peer-reviewed journals and giving numerous presentations at national meetings.

Dr. Dennis Albert (Central Michigan University) and Dr. Nick Danz (University of Wisconsin Superior) lead the wetland macrophyte sampling effort. They have conducted extensive research on plants in Great Lakes coastal marshes, with decades of experience in these systems. Dr. Albert led the macrophyte sampling and IBI development effort for the GLCWC effort. Dr. Danz has recently worked closely with Dr. Albert to refine coastal wetland macrophyte indicators.

Dr. Robert Howe (University of Wisconsin Green Bay) leads the bird and anuran sampling effort. Dr. Howe worked on the GLEI I and II projects and led the bird and anuran indicator development for those efforts. He has worked on bird monitoring for several decades and has published numerous peer-reviewed articles.

Dr. Jan Ciborowski (University of Windsor) is the regional leader for the central portion of the Great Lakes basin on the Canadian side. He served a similar role in the GLEI project and was a co-PI on a parallel project to define Reference Condition for Great Lakes coastal margin habitats, also greatly assisting with statistical data analysis. His specialty is aquatic macroinvertebrates, and he has decades of experience working on macroinvertebrates in the Great Lakes. He was a coauthor on chapters on macroinvertebrates, fish, water quality, and statistical design in the GLCWC final report. He has published numerous peer-reviewed articles and is also one of the co-coordinators of the Lake Erie Millennium Network.

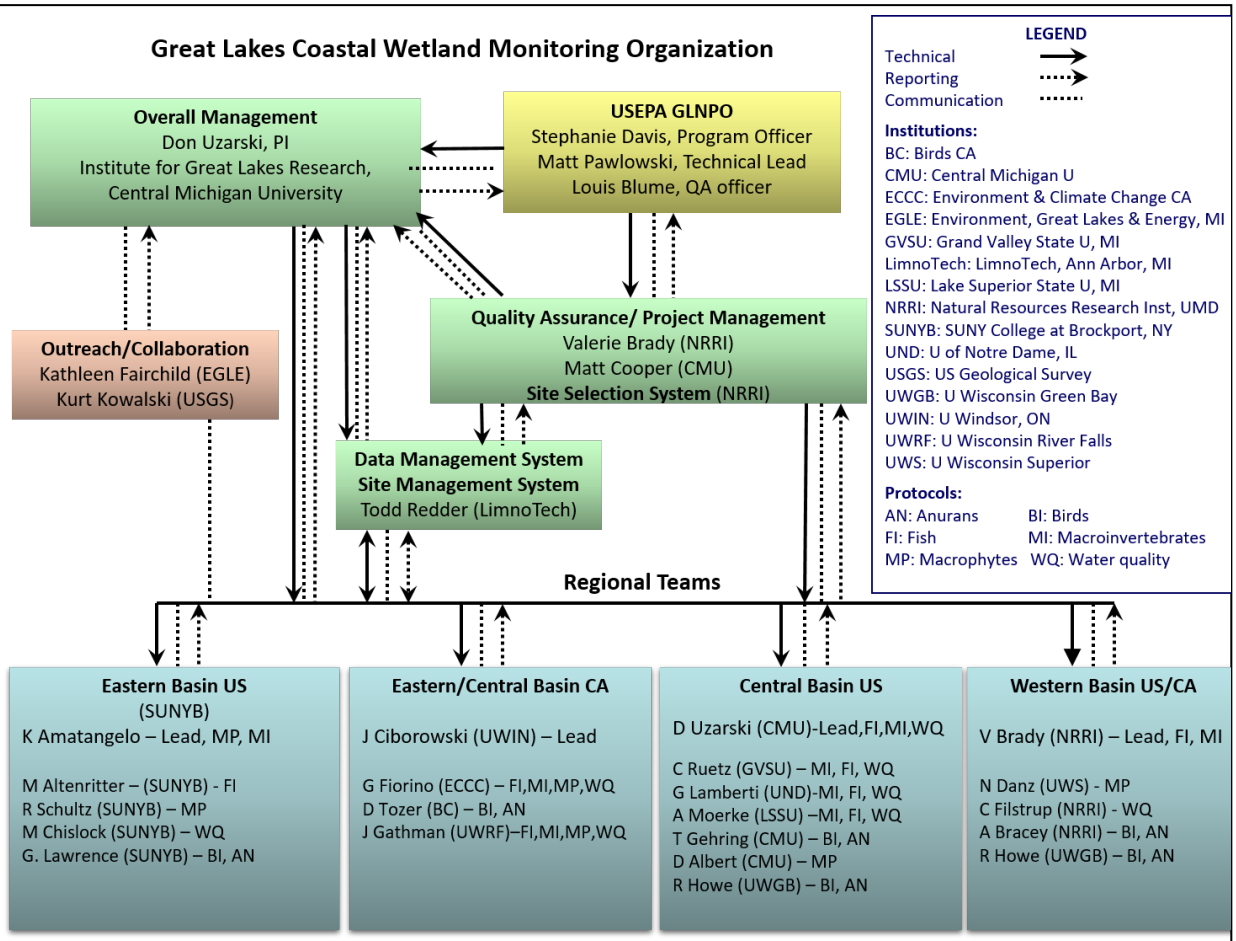


Figure 1. Organizational chart for the program showing lines of technical direction, reporting, and communication separately.

Roles and Responsibilities:

Dr. Don Uzarski (Central Michigan University):

- Lead PI, responsible for assuring all aspects of the sampling program are accomplished
- Partners with Gary Lamberti and Carl Ruetz for fish, macroinvertebrate, and water quality sampling for coastal wetlands across most of the state of Michigan
- Partners with Dr. Dennis Albert for macrophyte sampling
- Partners with Thomas Gehring for bird and anuran sampling
- Coordinates with Dr. Ashley Moerke (Lake Superior State University) for wetland sampling along the Michigan coast of Lake Superior
- Is responsible for all reporting to US EPA GLNPO and enforcement of QA/QC requirements

Dr. Valerie Brady (Natural Resources Research Institute, University of Minnesota Duluth)

- Program coordinator assisting with all aspects of program management
- Regional team co-leader for fish, macroinvertebrate, and water quality sampling in coastal wetlands in the western portion of the Great Lakes basin, including most of the coast of Lake Superior and the Wisconsin coast of Lake Michigan
- Partners with Dr. Nick Danz (UW Superior) for macrophyte sampling
- Is assisted by Dr. Chris Filstrup (NRRI) for water chemistry analyses
- Partners with Dr. Annie Bracey (NRRI) for bird and anuran sampling
- Works independently as QA manager to oversee QA/QC training and organize QA audits with the assistance of Dr. Matt Cooper (CMU)
- Oversees and manages the Site Selection System database; will oversee transition of Site Selection System to Central Michigan University to be re-coded as the Site Management System.
- Coordinates with the contractor to manage the data entry and data management system and program website

Dr. Robert Howe (University of Wisconsin Green Bay)

- Leads the bird and anuran sampling effort, coordinating with all regional team leaders and other bird and anuran specialists across the basin
- Coordinates with the bird and anuran leaders on other teams to organize training for bird and anuran field crews
- Reviews all bird and anuran QA/QC procedures

Dr. Dennis Albert (Central Michigan University)

- Leads the macrophyte sampling effort for the US Central Basin sampling team
- Coordinates with other macrophyte specialists on other teams to ensure proper training and QA/QC
- Trains other co-PIs on macrophyte metrics calculations

Dr. Kathryn Amatangelo (State University of New York at Brockport)

- Regional team leader for fish, macroinvertebrate, macrophyte, and water quality sampling in coastal wetlands of Lake Ontario and eastern Lake Erie
- Leads the macrophyte sampling effort for the Lake Ontario/eastern Lake Erie sampling team
- Is assisted by Greg Lawrence (birds, anurans, invertebrates), Dr. Matt Altenritter (fish), Dr. Michael Chislock (water quality), and Dr. Rachel Schultz (vegetation)

Dr. Jan Ciborowski (University of Windsor)

- Regional team leader for fish, macroinvertebrate, macrophyte, and water quality sampling in coastal wetlands of western US Lake Erie; Canadian shores of lakes Ontario, Erie, and the Huron-Erie connecting channels, and Lake Huron

- Is assisted by Dr. Joseph Gathman (University of Wisconsin River Falls)
- Collaborates with Giuseppe Fiorino and Ian Smith (Environment and Climate Change Canada) and Dr. Doug Tozer (Birds Canada)

Dr. Matthew Cooper (Central Michigan University)

- Assists in overall program management as part of the leadership team (with Uzarski and Brady)
- Assists Dr. Valerie Brady with QA/QC oversight and management
- Helps organize field crew training for all fish and macroinvertebrate field crews

Dr. Carl Ruetz (Grand Valley State University)

- Responsible for sampling of eastern Lake Michigan wetlands
- Serves as lead fisheries expert for the program

Todd Redder (LimnoTech)

- Manages Data Management System
- Will recode and manage the upgraded Site Management System

Dr. Kurt Kowalski (US Geological Survey)

- Will coordinate with CWMP crews for collaborative sampling at selected sites
- Will serve as liaison between CWMP and USGS

Kathleen Fairchild (M-EGLE)

- Organizes outreach and public information about the CWMP effort
- Organizes informational meetings about the program and its results with resource management agencies around the Great Lakes.

A5. Problem Statement

Coastal wetlands are critical components of the Great Lakes ecosystem, have suffered extensive degradation and loss over the past two centuries (Snell 1986, Krieger *et al.* 1992, Schaefer 1994, Environment Canada 2002), and have been greatly affected by land use and pollution (Bedford 1992, Wilcox 1995). Prior to the start of the Great Lakes Coastal Wetland Monitoring project in 2010 there was no routine monitoring program to determine the status and trends of Great Lakes coastal wetland condition at a basin scale. GLCWMP was begun as a project in 2010 to fill that gap and became a full-fledged monitoring program in 2017. To achieve this goal of routinely assessing the condition of Great Lakes coastal wetlands across the entire basin, we assembled a consortium of experienced coastal wetland scientists from the U.S. and Canada. We built this monitoring program on methodology previously developed, tested, and scientifically verified by the GLCWC and GLEI projects. Since 2010 we have efficiently and rigorously assessed and reported on the condition of coastal wetlands basin-wide and have created the baseline for temporal trend monitoring of wetland condition for each of the Great

Lakes. Our efforts now provide Great Lakes resource managers and decision-makers the critical information they need for strategic wetland protection and restoration policies that will ultimately improve the health of the Great Lakes ecosystem.

We are using the definition of Great Lakes coastal wetlands as in McKee *et al.* (1992): *"Wetlands may be considered to extend lakeward to the water depth of two meters, using the historic low and high water levels or the greatest extent of wetland vegetation. Hydrologic connections with one of the Great Lakes may extend upstream along rivers since exchanges caused by seiches and longer-period lake-level fluctuations influence riverine wetlands. Wetlands under substantial hydrologic influence from Great Lakes waters may be considered coastal wetlands."* The major types of Great Lakes wetlands that we are sampling are described in Albert *et al.* (2005) as follows: Lacustrine "wetlands are controlled directly by waters of the Great Lakes and are strongly affected by lake-level fluctuations, nearshore currents, seiches, and ice scour." Riverine wetlands "*occur along and within rivers and creeks that flow into or between the Great Lakes. The water quality, flow rate, and sediment input are controlled in large part by their individual drainages. However, water levels and fluvial processes in these wetlands are directly or indirectly influenced by coastal processes because lake waters flood back into lower portions of the drainage system. Protection from wave attack is provided in the river channels by bars and channel morphology. Riverine wetlands within the Great Lakes also include those wetlands found along large connecting channels between the Great Lakes*…" Finally, barrier-protected wetlands "*originate from either coastal or fluvial processes, but coastal nearshore and onshore processes separated these wetlands from the Great Lakes by creating a barrier beach or other barrier feature. These barriers may be active or part of relict coastal systems abandoned by the lake's margin. These wetlands are protected from wave action but may be connected directly to the lake by a channel crossing the barrier*…"

Recognition and appreciation of the importance of coastal wetlands in the Great Lakes ecosystem has grown markedly in recent decades as numerous important ecosystem functions have been ascribed to these habitats. For example, coastal wetlands provide critical breeding and migratory habitat for wildlife such as birds, mammals, reptiles, and amphibians (Austen *et al*. 1994, Hanowski *et al*. 2007a, Hecnar 2004, Mitsch and Gosselink 1993). These habitats are also critical spawning and nursery areas for many fish species of ecologic and economic importance (Jude *et al*. 2005, Chubb and Liston 1986, Klarer and Millie 1992). Additionally, coastal wetlands trap, process, and remove nutrients and sediment from Great Lakes nearshore waters, and recharge groundwater supplies (Burton 1985, Heath 1992). Accordingly, broad consensus has emerged among scientists, resource managers, and policy-makers on the importance of coastal wetland functions to the entire Great Lakes ecosystem. However, more than half of all Great Lakes coastal wetlands have been destroyed by human activities and many remaining coastal wetlands suffer from anthropogenic stressors such as nutrient and sediment loading, fragmentation, invasive species, shoreline alteration, and water level control (Burton 1985, Krieger *et al*. 1992, SOLEC 2007), as documented by a bi-national Great Lakes-wide mapping and attribution project (Albert and Simonson 2004 (Figure 2), Ingram and Potter

2004). Therefore, conservation of remaining coastal wetlands and restoration of previously destroyed wetlands are vital components of restoring the Great Lakes ecosystem. These efforts need to be guided by information on wetland conditions and trends.

A6. Program Description

Our primary objective is to continue and improve a standardized basin-wide coastal wetland monitoring program that has already proven to be a powerful tool for decision-makers for coastal wetland conservation and restoration priorities throughout the Great Lakes basin. Sampling methodology and indicator calculations follow and improve upon those that this team has implemented for the past 10 years of Great Lakes Coastal Wetland Monitoring (https://www.greatlakeswetlands.org/Sampling-protocols). Tasks include stratified-random site selection of coastal wetlands across the entire Great Lakes basin (Figure 2), sampling of selected wetlands (up to 20% per year for five years), data entry, data quality checks and clean-up, data uploading, and reporting to US EPA GLNPO. Wetland sampling involves collecting indicator data on birds, anurans, fish, macroinvertebrates, macrophyte vegetation, and supporting water quality measurements. All data are uploaded into a database specifically tailored for these monitoring results.

Regional sampling teams is led by Uzarski, Albert, Howe, Gehring, Moerke, Lamberti, and Ruetz (U.S. side, central GL basin); Ciborowski and Gathman, Fiorino and Smith, and Tozer (Canadian side, central and eastern GL basin); Brady, Bracey and Danz (U.S. and Canadian sides, western GL basin); and Amatangelo, Altenritter and Lawrence (U.S. eastern GL basin). Bird and anuran crews sample early in the season during the breeding period (early April - July), while fish, invertebrate, and vegetation crews sample June – mid September, moving from south to north as the vegetation and invertebrate communities develop. In most instances, the fish, invertebrate, and vegetation crews in each region travel together for efficiency and safety, sharing boats and other equipment and providing assistance to each other as needed. Regional team coordinators keep in close contact with their field crews via cell phone. The typical schedule each year is for site selection to occur during late winter. Field crews undergo training in the early summer (early spring for the bird/anuran crews), with field sampling occurring during mid-late summer (spring-early summer for bird/anuran crews). During the late summer, fall, and winter, samples are processed, data are entered into the program database, and QA/QC occurs on all data. Provisional data are provided to EPA GLNPO at the end of the field season (considered provisional until all QC validation is complete) and again at the end of winter after QA/QC checks have been completed (final data). Semi-annual reports are sent to GLNPO in the spring and fall (see detailed timeline in Table 1 for specifics).



Figure 2. Locations of Great Lakes coastal wetlands, based on GIS coverages created by Albert and Simonson (2004) and Ingram and Potter (2004). Map scale causes total wetland area to appear much larger than it actually is.

A7. Data Quality Objectives for Measurement Data

The primary DQO for this program is the acquisition of accurate and representative measurements of the biological, habitat, and supplemental water quality parameters for all major Great Lakes coastal wetland complexes, collected in accordance with established GLCWMP methods. It is very important that the data that we collect are representative of the condition of each wetland, are collected following GLCWP protocols, and are collected similarly by all field crews across the Great Lakes. Sampling methods, protocols, and indicators have already been approved for the GLCWP monitoring program. By following these methods, we generate representative and reproducible monitoring results.

In addition to all of the instructions throughout this document designed to help insure representative sampling, all field crews must be aware of how weather events can compromise sampling activities. In particular, riverine systems may experience high flows following storms which would compromise safe, efficient, and representative sampling. Sampling should not be

done until streams/rivers return to 150% or less of baseflow conditions. Crews can be assisted with this decision by accessing the nearest USGS gauging station flow records and consulting with their regional team leader. Similarly, high winds and waves can compromise lacustrine sampling and field crew safety. Crews should not attempt to sample during small craft advisories or if they are having difficulty setting fyke nets due to wave action. Crew leaders should determine which sites (from the list of sites assigned to their crew that year, see Section BA: Site selection) they can sample safely on any given day based on wind, weather, and wave conditions. In all cases, crews should not attempt to sample if there is any concern for their safety.

The co-PIs at each participating institution are responsible for the QA/QC aspects of the study, with training, oversight, and assistance from Valerie Brady and Matthew Cooper. Co-PIs conduct mid-season QA checks on their field crews and report the results to Brady and Cooper, who oversee these checks and other QA audits. Dr. Brady received QA/QC training as a post-doctoral associate at the US EPA Mid-Continent Ecology Division between 1997 and 2000. She subsequently worked on QA/QC for the GLEI I and GLEI II projects and the Estuarine and Great Lakes (EaGLe) Coastal Indicators Initiative (funded by US EPA STAR), and she and Cooper have attended all of the GLNPO QA/QC webinars offered by US EPA GLNPO.

Activities being performed during this monitoring round include 1) site selection, 2) sample and data collection of fish, macroinvertebrates, birds, anurans, macrophytes, and supporting water quality and habitat measurements, 3) laboratory identification of macroinvertebrates, 4) laboratory water chemistry measurements, 5) data processing and data entry into the database, 6) data QC, and 7) reporting to EPA GLNPO. All data collection follows the methods outlined in the GLCWMP QAPP and SOPs (https://www.greatlakeswetlands.org/Sampling-protocols). The DQO for data entry is 100% accuracy of data copied from field and laboratory sheets into the database.

For this monitoring round and sampling program, we are collecting monitoring data to be uploaded into a Great Lakes-wide database. Thus, we are doing limited data analyses and summarization on the collected data. Most data analysis focus on indicator calculation and indicator refinement. Thus, DQOs focus primarily on proper collection and handling of data and samples, and proper QC of data.

The scope of this program is all of the major coastal wetland complexes along the entire Great Lakes coastline, including Canada. Great Lakes coastal wetlands were mapped into a GIS layer by Albert and Simonson (2004).

Table 1. Timeline of tasks and deliverables for the Great Lakes Coastal Wetland Monitoring Program.

Tasks	2021				2022				2023				2024				2025			
	W	Sp	Su	F	W	Sp	Su	F	W	Sp	Su	F	W	Sp	Su	F	W	Sp	Su	F
Funding received	X																			
PI meeting	X				X				X				X				X			X
Site selection system updated	X				X				X				X				X			
Site selection for summer		X			X				X				X				X			
Sampling permits acquired		X				X				X				X				X		
Data entry system updated	X				X				X				X				X			
Field crew training		X	X			X	X			X	X			X	X			X	X	
Wetland sampling		X	X			X	X			X	X			X	X			X	X	
Mid-season QA/QC evaluations			X				X				X				X				X	
Sample processing & QC				X	X			X	X			X	X			X	X			X
Data QC & upload to GLNPO					X	X			X	X			X	X			X	X		X
Report to GLNPO		X		X		X		X		X		X		X		X		X		X
Site Management System update								X	X	X										

A8. Special Training Requirements

All personnel responsible for sampling invertebrates, fish, macrophytes, birds, anurans, and water quality are trained and certified before sampling begins each year. Several of the regional team leaders (co-PIs) have permanent technicians and staff who have years or decades of experience conducting aquatic sampling, which helps to ensure that rigorous data quality standards are maintained.

A multi-level training and certification program has previously been implemented and is being continued to ensure accuracy of all data collection. A series of training workshops led by regional experts on each respective protocol is held in the spring/early summer before fieldwork begins at several locations across the basin or online (birds and anurans) to ensure good attendance by the majority of field crew staff in each area. The workshop agenda includes training on how to meet the data quality objectives for each element of the program; QAPP review; site verification procedures; safety procedures including safe boating, trailering, and general field safety; hands-on training for each sampling protocol; procedures for entering data into the program database; record-keeping and archiving requirements; data auditing procedures; and certification/re-certification exams for each sampling protocol for all program personnel. All program co-PIs, field crew leaders, and as many summer staff as possible

participate in these workshops and are certified/re-certified on sampling protocols. Outside experts will be brought in for training if there are changes in co-PIs or as necessary.

To be certified in a given protocol, individuals must pass a practical exam. Training and exams are conducted in the field whenever possible, and are supplemented with photographs (for fish, vegetation) or audio recordings (e.g., bird and anuran calls) when necessary. Passing the exams certifies the individual to perform the respective sampling protocol(s). Because not every individual conducts every sampling protocol, participants are tested on the protocols for which they are responsible. The majority of testing and certification takes place during the early-season training workshops, and additional certification is administered by co-PIs as needed. Personnel who are not certified (e.g., part-time technicians, new students, volunteers) are not allowed to work independently nor to do any identification except under the direct supervision of certified staff members until they can pass the appropriate certification tests. The following paragraphs detail specific items that are covered during the training workshops each year. Preliminary certification criteria (minimum percent correct on certification exams) are also included below. For some criteria, demonstrated proficiency during the field training workshops is considered adequate for certification. Lists of who has received which training on what dates are created by each PI or training leader, sent to regional team leaders to compile, and are then provided to lead PI Uzarski and QA officers Brady and Cooper, who store these records electronically.

Note that the training and certification procedures explained here are separate from the QA/QC evaluations explained in section B. However, failure to meet program QA/QC standards may require participants to be re-trained and re-certified (see section C1 for corrective actions).

Site Selection and GPS Use: Field crews are trained to consistently locate pre-selected wetlands and sampling locations within each wetland, and are taught strategies to implement when pre-selected wetlands cannot be sampled due to insufficient water depth, unsuitable weather, inaccessibility, or safety concerns. Field crews also receive training in proper GPS procedures, including equipment use and data entry. GPS training includes extensive instruction on navigating to waypoints, creating waypoints, and determining levels of accuracy available.

Certification Criteria:

- Identify circumstances in which a site can be rejected as unsampleable (90%)
- Identify vegetation zones for stratified sampling (90%)
- Proper use of a GPS to navigate to a waypoint (demonstrate proficiency)
- Determination of GPS accuracy (demonstrate proficiency)
- Proper creation of a waypoint (demonstrate proficiency)

Fish: Training for fish sampling is led by the regional team leaders, co-PIs, and fisheries experts on the program. Fish sampling training focuses on teaching crew members how and where to set fyke nets (and problem-solving with net setting), how to process fish samples to minimize

harm to the fish, proper identification of fish, and when and how to collect voucher specimens for ID verification and QA/QC. Field crews are trained in proper fish handling procedures that meet both Institutional Animal Care and Use Committee (IACUC) and CWMP protocols. Crews are provided with identification guides and lists of fish species specific to the Great Lakes, including identification criteria for all known invasive species.

Certification Criteria:

- Selecting appropriate locations to set fyke nets (demonstrate proficiency)
- Setting of fyke nets (demonstrate proficiency)
- Proper handling of captured fish (demonstrate proficiency)
- Identification of fish species (90% of 20 species, either field-caught or photos, as necessary)
- Proper field data sheet completion (demonstrate proficiency)
- Preservation or photography of fish when a positive ID cannot be determined in the field (demonstrate proficiency in preservation and photography; 95% accuracy on determination of when to preserve)

Macroinvertebrates: Training for macroinvertebrate sampling and processing is led by regional team leaders, co-PIs, and macroinvertebrate experts on the program. Macroinvertebrate field work training focuses on training crew members in the proper selection of invertebrate sampling locations within the wetland, proper use of the D-frame dip net to collect macroinvertebrates, field picking organisms accurately, and preserving specimens with proper sample container labeling. Individuals who are sampling macroinvertebrates are required to pass a certification evaluation before working independently.

Additional training and certification is required for macroinvertebrate identification in the laboratory. Preliminary training at the pre-season workshop focuses on acceptable taxonomic reference materials, taxonomic resolution targets for all taxa, sample preservation and archiving, and record keeping. Use of taxonomic keys, etc., is not covered in the field training because invertebrate taxonomic training is conducted over the fall and winter by trained taxonomic staff (laboratory staff may not be the same as field crew staff). Temporary workers may be used for sample picking and processing, with QC and oversight by trained staff and laboratory managers. Invertebrate identification is carried out by trained staff that have done well in appropriate invertebrate identification coursework or similar previous training. All identification work is overseen by trained taxonomists on staff at each regional laboratory.

A crucial element of ensuring accurate invertebrate taxonomy is maintaining open dialogue among program teams. Our past experience has shown that many QA/QC violations can be avoided when laboratory personal communicate frequently. Such dialogue is an important part of both training and quality assurance. Laboratory staff use a variety of tools such as regular conference calls or webinars and e-mail sharing of digital photographs to foster this dialogue. Reference collections are maintained at each institution and are used for training staff

members. In addition to the open dialogue among team members, individuals participating in macroinvertebrate processing are required to obtain certification before working independently. Trainees must have 100% of their work checked by certified staff until they themselves become certified. Certification for laboratory processing of invertebrate samples is granted by a program PI skilled at working with macroinvertebrates.

Certification Criteria—Field Sampling:

- Determining sampling locations within a site (demonstrate proficiency)
- Appropriate dip net sampling technique (demonstrate proficiency)
- Field picking organisms (demonstrate proficiency)
- Preserving, labeling, and storing specimens (demonstrate proficiency)
- Proper field data sheet completion (demonstrate proficiency)

Certification Criteria—Laboratory Processing: (certification takes place as laboratory staff are hired and trained, rather than during field training)

- Sample handling/archiving (demonstrate proficiency)
- Record keeping (demonstrate proficiency)
- Data entry/data backup (demonstrate proficiency)
- QA/QC procedures (demonstrate proficiency)
- Taxonomic Identification (90% of at least 35 taxa)

Water Quality: Training for water quality sampling is led by the water chemistry experts on the program. Water quality sampling training focuses on proper calibration of water quality meters, proper collection of water samples to minimize contamination, proper field data sheet completion, proper labeling and treatment/preservation of samples, and packaging samples for shipping. Crews are also trained to recognize when meters are not functioning properly, how to code this on the field data sheets, and basic trouble-shooting techniques. A basic understanding of aquatic ecology/limnology gained either by having taken appropriate undergraduate coursework or equivalent on-the-job training is a prerequisite for leading water quality data collection. Water quality analyses in the laboratory are conducted or supervised by highly-trained individuals with years of experience.

Certification Criteria:

- Calibration of water quality meters (demonstrate proficiency)
- Use of water quality meters (demonstrate proficiency)
- Trouble-shooting of meters (demonstrate proficiency)
- Ability to approach sampling point without disturbing sediment
- Ability to recognize when sampling point sediment has been disturbed at water quality samples cannot be collected from that point on that day
- Collection and storage of water samples (demonstrate proficiency)
- Proper field data sheet completion (demonstrate proficiency)

Macrophytes: Macrophyte sampling training is led by regional team leaders, co-PIs, and aquatic macrophyte experts on the program. Training includes proper transect establishment, location of random sample plots, aquatic vegetation taxonomy, protocols for dealing with problematic identifications, and when to take samples for QA/QC. The collaborators in this program have done extensive plant sampling in Great Lakes coastal wetlands, so their species lists, picture keys, and field data forms include most plants that are encountered during the program. The species lists also include all of the major invasive plants known from coastal wetlands. Reference materials at university herbaria are available for comparison. Plant materials that cannot be positively identified in the field are collected for identification that evening or pressed for later identification in the laboratory. Additionally, at QC sites, plants are collected for QC checks later. One of the most difficult aspects of plant sampling in quadrats is accurate estimation of the percent coverage for plant species present. Teams calibrate the estimation of plant coverage as a group during training.

Certification Criteria:

- Transect and plot locations (demonstrate proficiency)
- Taxonomy (75% of 20 species identified in the field; 90% of 20 species, using appropriate identification guides in the laboratory)
- Total percent cover by vegetation within quadrats (sampling team estimate of coverage ±10% of an expert's estimate 90% of the time)
- Determining when to collect voucher specimens for identification in the lab (demonstrate proficiency)
- Proper preservation procedure for specimens (demonstrate proficiency)
- Proper completion of field data sheets (demonstrate proficiency)

Birds and Anurans: Bird and anuran sample testing and training is provided by regional team leaders, co-PIs, and bird and anuran experts on the program. These individuals have been testing and training students and personnel to conduct bird and anuran surveys for many years. Survey personnel are evaluated and hired based on their demonstrated proficiency in visual and aural identification of Great Lakes bird and anuran species and familiarity with the survey protocols. Candidates are evaluated using audio and visual tests and trained in field-based survey techniques. An objective, secure online testing system (http://www.birdercertification.org) has been modified for target anuran and bird species found in the study areas. The bird certification website was developed by Dr. Howe of UW-Green Bay in response to the need for testing and training individuals in bird identification. Bird and anuran personnel are also required to demonstrate their knowledge of the survey protocols prior to field activities. Field tools (portable audio players with bird vocalizations, which, when broadcasted into the marsh, elicit calls from secretive species) are provided to field teams and standardized among survey groups.

Because active ornithological research programs are ongoing at each of the participating institutions, a pool of qualified personnel for bird surveys is available or recruited for fieldwork. Acceptable candidates typically have taken a college-level course in ornithology and have field experience in bird surveys through research projects or volunteer opportunities. Candidates for the fieldwork typically have participated in monitoring programs such as the Marsh Monitoring Program, State or Provincial Breeding Bird Atlases, North American Breeding Bird Survey, or other state or regional monitoring programs.

Skills in anuran identification are more easily acquired than bird identification skills because the diversity of species in the Great Lakes basin is relatively small (Harding 1997). Prior to the training sessions, lead researchers provide audio CDs or web links of frog and toad vocalizations to trainees so that they can study for tests to be given during field training. During field training, lead researchers describe known habitat associations of anuran species in the Great Lakes basin. Bird and anuran personnel are allowed to retake the test a maximum of 3 times with a minimum of 1 day between subsequent tests. If they do not pass the test on the third attempt, personnel can only assist bird and anuran team leaders in sampling and cannot collect data on their own. They may re-attempt the test the next season.

Certification Criteria:

- Survey plot locations (demonstrate proficiency)
- Visual identification (95% of 20 bird images, including difficult views, immature plumages). This test focuses on species likely to be seen rather than heard.
- Aural identification (90% of 30 bird species; 100% for focal species; 15 of 16 calls correctly identified for calling anuran species)
- Proper completion of field data sheets (demonstrate proficiency)
- Appropriate demonstration of how to document calls/species that cannot be readily identified (demonstrate proficiency)
- Audio testing includes a range of species with songs at varying frequencies and volumes to insure adequate hearing by field crews.

Record Keeping, Data Custody, and Data Entry: Brady (NRRI) and Cooper (CMU) have previously led training on record keeping, sample chain of custody, data custody, and entry of data into the data management system. This portion of the training also included data error checking protocols. These reminders now occur during the annual program meetings and via email reminders and QC checks on data and record keeping.

Additional Training:
Permanent technicians and staff who are designated as crew leaders assist regional team leaders (co-PIs) in training temporary summer workers who are not able to attend the field crew training. By providing field crew training at several locations around the basin, most summer workers are able to attend the training. Uncertified workers always (100%) work with

more experienced personnel until they pass certification and receive substantial training until they prove themselves competent in field sampling methods.

Regional team leaders (co-PIs) accompany field crews to 10% of wetland sites each year to ensure that all data collection methods are being done according to established protocols. Brady and Cooper archive the reports of these mid-season QC activities and summarize the results in the semi-annual report to EPA (and to all co-PIs). They inform Uzarski and co-PIs of any deficiencies and the required corrections. Follow-up reports from co-PIs demonstrating correction of these deficiencies are required.

A9. Documentation and Record

We have created a specialized data management system dedicated to GLCWP wetland monitoring data. For each wetland, data include 1) a GIS polygon layer showing wetlands sampled each year; 2) geographic locations of all sampling points within each site by taxa group; 3) macroinvertebrate identifications, counts, and IBI scores; 4) fish identifications, counts, and IBI scores; 5) macrophyte identifications, coverages, and Conservatism values; 6) water quality data; 7) bird identifications and indicator values; and 8) anuran identifications and indicator values. The database is housed at CMU and accessed on-line. Data "uploading" to the data management system is synonymous with data entry. QC of field crew sampling and data collection by PIs occurs once per year during the sampling season. QC of laboratory activities and data input by laboratory leaders occurs each winter. All QC records and reports are maintained with the appropriate datasets, archived, and provided to the QC managers (Brady and Cooper) during audits. Data are put into the database and QC'd as soon as possible after data are collected. Data are made available to EPA annually after QC checks are completed. This data management system also contains metadata for each data type, including study design, site selection, and reason for rejection of sites that cannot be sampled.

The semi-annual report to US EPA GLNPO consists of all activities of the previous 6 months, including QC reports and audit results, and brief data summaries. However, the data are made available in the database, rather than in the report itself.

Records from field and laboratory observations are archived as hardcopies at each regional lab. All data entry on the web-based system will remain accessible throughout the life of the program. Copies of formal reports and supporting materials are archived in CMU libraries and identified with CMU technical document coding for future retrieval. Sample sheets completed on-site during field sampling and all field sheets, logs, chain of custody documents and sample materials will be retained by CMU and regional labs for a minimum of three years, or made available after that time period.

<u>Deliverables list:</u>

- Semi-annual report to EPA twice per year (including QC reports)

- Data provided to GLNPO twice per year (see above for data included; includes metadata)
- Indicator values for all sampled wetlands, provided once per year
- GIS files of site locations and sampling points, provided twice per year
- Final report to EPA
- Final QA/QC report including all difficulties encountered and their solutions

B. DATA ACQUISITION

BA. Site Selection

BA1. Program Design

The project on which this sampling program is based, the Great Lakes Coastal Wetland Consortium (GLCWC 2008) developed a statistically-sound probabilistic site selection design that allows statistically-valid prediction of overall Great Lakes coastal wetland condition and trends based on a subset (one 'panel') of sites being sampled. The design is similar to the EMAP system for streams and lakes.

When this sampling program started in 2010/2011, the NRRI GIS laboratory implemented a framework for probabilistic site selection. The initial pool of wetland sites was based on the GLCWC-GLNPO wetland coverage (Albert and Simonson 2004). Wetlands selected for inclusion in our program's sampling framework under the random site selection process needed to meet the following criteria: 1) 4 ha or larger; 2) have a direct, obvious surface water connection to a Great Lake or connecting channel allowing fish passage at least every year or so; 3) be close enough to that lake or connecting channel to be influenced by it (e.g., seiches); and 4) contain herbaceous or standing-water wetland zones.

Size > 4 ha: Previous basin-wide work by GLCWC and GLEI field crews indicated that smaller wetlands can be either too small to sample, or no longer in existence.

Surface connection required: Fish, aquatic macroinvertebrate, and to some extent vegetation metrics and indicators are influenced by which fish can access the wetland. Our metrics and indicators are calibrated based on fish having access to the wetland at least intermittently.

Distance from the lake for lake influence is difficult to quantitatively define. In general, influence of the lake does not transmit more than about 1 km upstream or away from the lake (much less so if the shoreline gradient is steep), so if the wetland is less than this distance from the lake or connecting channel and the vertical relief between the lake level and the wetland is less than 2 m, then the wetland should be evaluated for potential sampling. The exceptions tend to occur in drowned river mouths along the eastern coast of Lake Michigan. If water is at

the same level all the way across these river-mouth lakes, then the wetlands at the inland end of the lake will still be influenced by the Great Lake and are considered Great Lakes coastal wetlands and thus are included in our sample pool. In all cases for riverine wetlands, the most downstream portion possible is sampled, whether this occurs on the Great Lake side or the inland side of the drowned river mouth lake.

Herbaceous vegetation presence: We have not yet developed or evaluated indicators and sampling protocols for use in wooded wetlands. Sites lacking aquatic vegetation do not qualify for sampling in this program.

In 2011 we designed our site selection as a stratified-random design based on 1) wetland type (riverine, lacustrine [open fringing], barrier-protected; Albert *et al.* 2006); 2) region (northern and southern, including geopolitical boundaries); and 3) Great Lake. Additional sites outside the probabilistic design may be added to the sampling list each year with approval from EPA GLNPO. These “benchmark” sites include sites being considered for or undergoing restoration and/or protection to assist other agencies in determining which sites should be selected for restoration and protection efforts. Including benchmark sites within a statistically-valid monitoring framework allows agencies to determine where their sites of interest fall on the condition spectrum of Great Lakes coastal wetlands.

Up to 10% of sites sampled in any given year can be benchmark sites that fall outside the stratified random site selection framework without invalidating the statistical framework. Benchmark sites are sites of special interest that have been requested for sampling. Many are sites that are undergoing (or have undergone) restoration; some were not even wetlands prior to restoration work. In addition, some sites from the stratified-random pool are sampled more frequently than once every five years because they are long-term monitoring sites (from the 1990's) and the extra data from these sites is used to help evaluate our indicators and metrics, particularly for interannual variability and effects of changing water levels. Criteria for inclusion of benchmark sites are the appropriateness of the request and our sampling methods for assessment of the site; the potential of the site to become a coastal wetland if it is not one already, our ability to sample the number of benchmarks requested, and EPA's approval of the sites proposed for benchmark sampling each year. Sites that are outside the site selection framework will not be used in condition assessment methods.

BA2. Sampling Methods

The site selection process outlined above resulted in clusters of sites for each lake (or lake section where lakes cross the regional boundaries); clusters are defined by the 3 wetland types, 5 lakes, and regions (e.g., northern Lake Michigan riverine wetlands; southern Lake Huron lacustrine wetlands; etc.). An estimation of the number of wetlands within each cluster is shown in Table BA2-1; which of these can actually be sampled depends on lake water levels and safe access by crews and varies from year to year. To set up site selection, in 2011 each regional team leader used the site selection web-based app to virtually investigate each site in their

region via satellite imagery and deliberately selected or rejected the site for sampling. Sites could only be rejected for very specific reasons, such as that it was too small, had no safe access, etc. (see section BA5 for complete list of acceptable site rejection criteria; Brady, Cooper, and Uzarski verified that regional leads did not inappropriately reject sites).

BA2-1. Approximate number of wetland polygon counts by type and lake section. These are estimates of the number of wetlands and are probably higher than the actual number because of changing numbers of sampleable wetlands each year based on lake levels and human activity.

Lake Section	Lacustrine	Barrier-protected	Riverine	Total
Superior (all)	33	88	77	198
Michigan (N)	71	114	51	236
Michigan (S)	1	21	20	42
Huron(NW)	103	32	60	195
Huron (SW)	31	7	4	42
Huron (CA)	183	94	81	358
Erie (CA)	17	15	32	64
Erie (US)	36	5	43	84
Ontario (CA)	57	53	83	193
Ontario (US)	13	45	59	117
Totals	**545**	**474**	**510**	**1529**
Est. Sampleable				**1100**

In addition to assessing which sites fit our sampling criteria, regional team leaders also assessed whether wetlands had been artificially divided into separate sampling polygons due to human influence or other causes. If the minimum edge-to-edge distance of the wetland polygons in question was 500 m or less and the wetlands were of the same basic type (e.g., lacustrine, barrier-protected, or riverine), these polygons were evaluated by Brady and Cooper for dissolving the separate polygons into a single wetland polygon for sampling.

The opposite case could also occur, in which PIs noticed that wetland polygons were inappropriately lumped together when they really were separate wetlands because of differences in water flow, lack of connectivity, or incorrect assignment of wetland site type (lacustrine, barrier-protected, riverine). Brady and Cooper evaluated these cases and created separate polygons for these “lumped” wetlands as appropriate.

The vast majority of such changes to the wetland polygon coverage took place the first two years (2011-2012) of the project and there have been few changes to the polygon coverage since that time except to add additional sites that were missed originally or to add benchmark sites that are undergoing restoration and aspire to become coastal wetlands in the near future.

Following all of the initial (2011) site assessment for appropriateness of sites for our condition indicators, size, connectivity, site access, and appropriateness of site polygons, sites were

assigned to sampling panels, one panel for each of the five years of a monitoring round. Sites were randomized within each cluster (again, clusters defined by the 3 wetland types, 5 lakes, and N/S regions) and distributed across the five sampling panels, each panel representing the sites to be sampled in each of the five years in a monitoring round.

The sites in each sampling panel form the basis of a five-year rotating panel design, populated by the sites that have a high probability of being sampleable in any five-year sampling round. This design ensures that all major wetlands are sampled over a period of approximately five years. This stratified-random site selection process assures that the condition of Great Lakes coastal wetlands basin-wide can be inferred and statistically summarized based on the outcome of a single year's sampling (benchmark sites that are outside of the sampling design are excluded from these calculations).

Each field season, each regional sampling team systematically examines their assigned set of sites from the randomly ordered site list for that year, provided to them by the web-based app, the Site Selection System. Teams may still reject sites that fail to meet the minimum criteria, either by assessment of aerial photos or once the sites are visited in the field. For example, sites that are accessible by boat for fish, macroinvertebrate, vegetation and water quality sampling may not be accessible from the land for bird and anuran crews due to lack of road access; this can be determined via aerial photography. On the other hand, it can sometimes be difficult to determine via aerial photography whether or not barrier-protected wetlands have a surface water connection to the lake and these sites may require in-person assessment by field teams.

Support for site selection is provided by the NRRI GIS lab through 2022. This facility contains a number of computers running the latest ESRI ArcGIS software. Hardware systems are typically Intel or AMD multi-core processors running at 2.4+ GHz with 0.5+ TB of local storage. Internal and internet networking is 1000 MB (1 GB) Ethernet, with 40 Mbit/s Internet connectivity. The use of ArcMap 10 (Bing maps), QGIS (Google, Yahoo, and OpenStreetMap), and existing collections of Great Lakes coastal imagery developed previously allow interpretation of sites before field work, and verification of GPS information received from the field.

The current Site Selection System is written in outdated code and software and in desperate need of updating. In late 2022 and 2023, the system will be re-coded by LimnoTech to ensure that it works well on modern servers and includes updates that will allow it to interface well with the map images needed by all teams. NRRI will work with LimnoTech to ensure a seamless transition between the old and new system (which will be renamed the Site Management System (SMS)). The features of the existing system will be ported to the new system in order of highest to lowest priority, based on guidance provided by NRRI. Examples of high-priority features include viewing and editing site tags and other details, applying site filters, and viewing/updating site status lists. Development and testing of each Site Management System feature will be conducted following the step-wise approach outlined below:

1. A draft implementation of each feature will be completed by LimnoTech.
2. Prior to testing of a feature, site tagging, comments, and other data will be synced from the NRRI database to the master database that supports the Data Management System (DMS). This will ensure that both systems are operating on the same datasets and that direct comparisons can be made.
3. "Alpha" testing of each feature with be conducted by LimnoTech. Although the specific approach will vary somewhat depending on the nature of the feature, this testing will generally involve: 1) direct comparison of data displayed in each system for at least five different sites, and 2) targeted testing of features that involve updating site information in the database based on user selections or other inputs via the SMS user interface.
4. LimnoTech will incorporate any revisions to SMS features based on the findings of the "alpha" testing effort.
5. "Beta" testing of individual features will be conducted by NRRI staff and select members of the broader CWMP team that are involved with site management efforts. This aspect of testing will involve not only ensuring that the site data are accurately portrayed and can be properly updated in the new system, but it will also highlight any usability concerns or potential enhancements. Beta testing will include attempting to "break" the system by doing things incorrectly, attempting to do things that should not be allowed, etc., to ensure the system is robust to these types of things.
6. The features of the new SMS will be finalized by LimnoTech based on feedback received by NRRI and other test users. NRRI and LimnoTech will jointly determine the relative priority of revisions/enhancements proposed by test users, recognizing that some updates may need to be addressed at a later time.
7. Testing results will be documented in a brief technical memorandum that will be shared with the CWMP lead PIs and USEPA.

The SMS will be deployed and made accessible to "Level 4" users via the main CWMP website. The new system will be housed on a Central Michigan University server, rather than at NRRI, so that CMU will maintain servers containing both this system and the DMS. At the time of transition from the existing NRRI system, the master CWMP database on the CMU server will be updated with the latest site management-related information contained in the current version of the NRRI database. Given that the need to begin site management activities for the 2023 monitoring year is imminent (February 2023), our plan is to have the new SMS fully developed, tested, and ready for use no later than October 2023. This timing will allow for the necessary transition and training period to occur during fall/winter 2023-24, such that the new SMS can completely replace the NRRI system for all 2024 site management activities. Once the system has been fully ported to the CMU server where the DMS is hosted, further maintenance of the system will be conducted by LimnoTech on a routine basis alongside maintenance of the DMS. The NRRI system will be maintained until it is clear that the new system at CMU is fully operational and functional. However, only one system will be in use as the primary system at any one time to avoid confusing users.

BA3. Sample Handling and Custody

Regional team leaders are provided with appropriate materials (wetland maps, GPS coordinates for sampling points, boat access, etc.) in advance of the field season to facilitate sampling and travel logistics and permit preliminary site reconnaissance (the bird and anuran crews are often able to assist with site reconnaissance for the fish/invertebrate/vegetation crews). On-line web-based distribution of maps for each site showing site outlines and the location of nearby sites to ensure sampling within targeted site boundaries, pre-determined sampling points (bird/anuran crews) and transects (vegetation crews) allow efficient and rapid distribution of materials to field crews scattered across the basin. SOPs for each team specify how to determine if each crew has arrived at the proper point (bird/anuran crews), transect starting location (veg crews), or overall polygon (fish/invertebrate/water quality crews). Crews are also trained on when and how to move these points or transects should they not be located close enough to the wetland (bird/anuran points) or at an appropriate water depth (vegetation transect start/end points). Crews are also trained to call their team leader for assistance in these instances. Centralized site selection and map creation ensure maximum efficiency and a dedicated source of map and logistical assistance.

For planning purposes, the numbers of samples that could be expected per site is shown in Table BA3-1. These numbers are only estimates because for all sample types except vegetation, the number of samples varies depending on site size (all non-veg samples) and appropriate vegetation types and water depths (fish/invertebrates/water quality). Vegetation crews always sample 45 quadrats per site.

BA3-1. Estimated mean number of samples per site by sample type, and the number that might require laboratory processing. For fish, vegetation, birds, and anurans, samples requiring processing refers to estimated numbers of unidentifiable taxa or calls that require extra effort after the field sampling in order to be identified.

Sample Type	Samples/site	Composites/sample	Requiring processing
Fish	6	0	1
Invertebrates	6	~10	6
Vegetation	45	0	5
Water quality	2-4	typically 3	2-4 composites
Birds	4	0	0
Anurans	2	0	0

For planning purposes, the numbers of samples that regional teams can expect each year by sample type is estimated in Table BA3-2. Again, these are only estimates because the number of samples per site varies for all but vegetation crews. Numbers were derived by multiplying estimated mean numbers of samples per site by the site sampling capacity of teams (team sampling capacity includes benchmark sites). Team sampling capacity is static from year to year

and is based on budgetary allotment for the crew, which is based on the geographic area that each regional team is responsible for.

BA3-2. Estimated mean number of samples per year by team and sample type for planning purposes, with samples requiring lab processing shown in parentheses (for fish, vegetation, birds, and anurans, these are the estimated numbers of unidentifiable taxa or calls that are returned to the lab for identification). Numbers were derived by multiplying estimated mean numbers of samples per site by the sampling capacity of teams. Team sampling capacity is typically static from year to year.

Team	Fish	Inv	Veg	WQ	Bird	Anuran
Uzarski *et al*.	240 (40)	240 (240)	1400 (100)	80-160 (80-160)	320 (20)	160 (5)
Brady *et al*.	180 (30)	180 (180)	1050 (150)	60-120 (60-120)	160 (10)	80 (2)
Ciborowski, Fiorino *et al*.	210 (35)	210 (210)	1225 (70)	70-140 (70-140)	160 (10)	80 (2)
Amatangelo *et al.*	180 (30)	180 (180)	1050 (70)	60-120 (60-120)	160 (10)	80 (2)

BA4. Analytical Methods Requirements

Performance criteria: Regional team leaders have been trained on the parameters for site rejection (see section BA5), and the management team provides QC oversight on this aspect of the program. Sites that appear to be inappropriately rejected are the subject of a discussion between the regional team leader and the management team. Target turnaround time for initial site assessment via aerial photography and previous notes about the site is one month prior to the field crew beginning fieldwork to allow for discussion and re-inclusion if sites were inappropriately rejected. Inappropriate site rejections made by field crews on the ground typically cannot be corrected in time for sampling that field season if not discovered in real time. Thus, all field crew leaders are trained to consult with their PI and/or the CWMP leadership team before rejecting a site to prevent inappropriate site rejections.

Database system requirements: Hardware systems are typically Intel or AMD multi-core processors running at 2.4+ GHz with 0.5+ TB of local storage. Internal networking is 1000 Mbit (1 GB) Ethernet, with 40 Mbit/s Internet connectivity. This applies only to the NRRI computer systems that house the site selection database. Because of the backups provided with this system (see section B10), failure of any component will not result in loss of data. The redundancies built into the system allow the system to be brought back on-line by NRRI GIS lab and IT staff with a minimum of delay. Any computer with internet access can access the site selection system database as long as the computer user has a password and clearance.

With the rebuild of the system and the transition to Central Michigan University (CMU) servers, the revamped Site Management System in 2023 will be running alongside the CWMP Data Management System (DMS) on a Windows Server 2019 virtual machine (VM) managed by CMU's IT staff and maintained by the CWMP Data Manager. The hardware specifications of the server include an Intel® Xeon® E5-266 v3 @ 2.30 GHz CPU, 8 GB of RAM, and 0.25+ TB of local

storage. Internal networking is mixed 100/1000 Mbps and 10 Gbps Ethernet, with two 10 Gbps Internet connections. The VM described above hosts or will host all components of the CWMP DMS and Site Management System, including the web application, the (PostgreSQL) database server, and the (GeoServer) geospatial server. This single-server configuration streamlines maintenance activities and backup protocols.

BA5. Quality Control Requirements

Regional team leaders inspect aerial photographs and other information (e.g., site access points) for each site as they make the decision whether to accept or reject sites for sampling in any given year. Sites can only be rejected for specific reasons to ensure that sites are selected randomly rather than deliberately. Reasons for site rejection are limited to: 1) site is too small (< 4 ha); 2) site is known to be dry or to no longer exist as a wetland; 3) site does not have a surface water connection to the lake navigable by fish at least every other year; 4) there is no safe access for field crews (e.g., no public launch within approximately 7 km); and 5) there is no permitted access due to private property constraints. Most of these conditions do not result in permanent rejection of sites because these conditions are often subject to change based on water levels, crews obtaining better boats or gear, or land ownership changing. Only condition #1 (site is too small) and permanent destruction of a wetland (#2b) result in exclusion of a wetland from consideration for future sampling. Most exclusions in category #1 were made at the start of the program in 2011 and few sites now are excluded due to size. Sites are not permanently excluded from sampling consideration based on vegetation responses to water levels.

Crews have different access issues (#4 and #5 above) based on how and what they sample. Fish/invertebrate and some vegetation crews work from boats and need boat launches within safe boating distance over the open waters of the Great Lakes. Bird/anuran crews, on the other hand, typically hike in from land and need safe road and trail access in the dark and permission to cross private property. In addition, bird/anuran crews can sample sites more quickly than can fish/invertebrate/vegetation crews, allowing bird/anuran crews to sample more sites than the other crews. Because bird and anuran crews are the first in the field each season, their observations of site access assist fish/invertebrate/vegetation crews.

Individuals primarily responsible for site selection/rejection by regional field team:

Western Great Lakes	Valerie Brady/ Annie Bracey /Nick Danz
Central Great Lakes (US side)	Don Uzarski/Carl Ruetz/Robert Howe/Tom Gehring
Central Great Lakes (CA side)	Jan Ciborowski/Joseph Gathman/Doug Tozer/Annie Bracey
Eastern Great Lakes (US side)	Kathryn Amatangelo/ Greg Lawrence/Matt Altenritter
Eastern Great Lakes (CA side)	Jan Ciborowski/Joseph Gathman/Giuseppe Fiorino/Doug Tozer

<u>Site selection QC check:</u>

Because regional team leaders are responsible for accepting/rejecting sites from lists generated by the site selection system, a quality control step has been implemented to ensure that consistent criteria are used by each team to reject sites. The program lead PI (Don Uzarski, Central Michigan University), QA manager (Valerie Brady, NRRI), or assistant QA manager (Matthew Cooper, Central Michigan University) examine the list of rejected sites within the site selection system and determine if these rejections are consistent with the criteria above and that the criteria are being applied consistently across the basin. Corrective actions are detailed in section C1.

BA6. Instrument/Equipment Testing, Inspection, and Maintenance Requirements

The Site Selection System is currently running in the NRRI GIS lab. The NRRI GIS lab automated backup systems are monitored on a daily basis to ensure immediate repair of any failed components or processes. Combined with the redundancies built into the system, this ensures equipment or system failures will not have an unrecoverable impact on the site selection process.

One of the key benefits of integrating the upgraded Site Management System (SMS) with the DMS is that a unified approach can be used to archive and back up both systems, including the web application, the PostgreSQL database, and the geospatial server components that support both systems. The virtual server that houses the DMS has been configured to use CMU's Veeam Backup Solution, and full and incremental snapshots are taken and stored on a local backup server at CMU. Incremental backups are performed nightly and stored at secure locations (on premise and offsite). End-to-end encryption is used for any data that are copied or moved from the backup server to an off-site location. Nightly backup email reports are generated and sent to appropriate CMU IT staff for monitoring purposes. Full system or volume restores can be performed via the previous full snapshot as required. Incremental backups are maintained in the time intervals between full snapshots, which allows for the immediate recovery of folders and individual files in the case of accidental deletion or hardware failure.

Additional backup measures for individual components of the DMS and SMS are managed by LimnoTech and include: 1) a full nightly SQL backup of the PostgreSQL database and upload to a secure cloud storage service (Sharefile), and 2) storage and source code version control for the CWMP web application in a GitHub repository. Nightly database backups are stored for a period of 30 days. The current backup systems provide some redundancy and ensure that minimal data loss (< 1 day) will occur in the event of a hardware or software failure.

BA7. Instrument Calibration and Frequency

N/A

BA8. Inspection/Acceptance Requirements for Supplies and Consumables

N/A

BA9. Data Acquisition Requirements (non-direct measurements)
Sources for external datasets of all types will be tracked. However, at this point in the life of the program, few external datasets are used. If we use an external data source, it will likely be from peer-reviewed publications and GIS sources with established metadata lineages; these lineages will be maintained. In rare cases in which unpublished data are used, appropriate metadata will be generated to describe its origin. All such data will be checked for appropriateness of QC for our program's standards.

When this sampling program started in 2010, the wetland site coverage used was based on the Albert and Simonson (2004) Great Lakes coastal wetland GIS coverage. Use of this database for site selection was mandated in the original RFP and by the necessity of following the original GLCWC sampling protocols. To turn this coverage into sampleable wetland polygons required extensive work and QC in the first year of the project and we maintain and update this layer.

Other data used for site selection included wetland type (Albert *et al*. 2006) and GIS background layers (roads, boat launches, land use, etc.) from state and federal agencies that we use to make maps for crews navigating to site polygons.

Land use data for calculation of the land use and water quality indicator come from the North American Land Change Monitoring System (NALCMS) 2010 land cover of North America at 30 meters (from Landsat imagery) (CEC 2015). The NALCMS is a collaborative initiative by agencies across the U.S., Canada, and Mexico to monitor land cover change and is produced by the multi-national Commission for Environmental Cooperation (see citation for partner organizations). These land cover data are published and provided as a tool for researchers and meet the QC standards of the associated agencies, including the U.S. Geological Survey. Because the NALCMS includes land cover for both the U.S. and Canada, it standardizes the land cover calculations across all CWMP sites.

Non-peer-reviewed information, such as the aerial photos, will be visually checked for site location by comparison with the appropriate quad map or Google maps. These photographs will be used as supplemental guidance for field crews rather than to actually generate data. All of the data types mentioned above are in the public domain and are not subject to use restrictions.

BB. Water Quality

Please refer to CWMP water quality SOPs for greater detail and step-by-step instructions, available on the CWMP website: https://www.greatlakeswetlands.org/Sampling-protocols.

BB1. Program Design

Chemical/physical measurements are made in each vegetation type where fish and macroinvertebrate data are collected, but may also be collected in areas too shallow or deep for fish or macroinvertebrate collection. Fish and macroinvertebrates are collected within vegetation morphotypes (see Sections BC and BD); water quality is collected in association with fyke nets, one water quality sample per vegetation type sampled. In the event that fyke nets are not set due to inappropriate water depth, but invertebrates are collected, then a water quality sample is also collected from that vegetation type. These samples are required. Crews have the option of taking water quality meter samples at each individual fyke net location (or invertebrate dip net replicate point if fyke nets are not set). This additional sampling effort is recommended if vegetation patches forming the sampling type are separated rather than contiguous. Water quality data collection is critical at each wetland, but parameters are classified as critical, recommended, or supplementary on an individual parameter-by-parameter basis in this section. Defining parameters as "critical" does not mean that biological samples should not be taken at a site if water quality parameters cannot be taken because, for example, the DO sensor on the meter is malfunctioning. Every attempt should be made to get critical measurements, including borrowing equipment from a nearby field crew and obtaining a replacement meter as soon as possible. We also define water quality parameters in terms of 1) field measurements using instruments with sensors used at the site, 2) parameters requiring analysis of a water sample either the evening or the day after the sample was collected, or 3) parameters measured at one of our water quality laboratories.

Critical:

- Field: temperature, dissolved oxygen, pH, specific conductivity
- Lab: alkalinity, turbidity, soluble reactive phosphorus (SRP), [nitrate+nitrite]-nitrogen, ammonium-nitrogen, chlorophyll-a

Recommended:

- Field: secchi tube water clarity
- Lab: total nitrogen (TN), total phosphorus (TP), chloride, color

Supplementary:

- Field: oxidation-reduction potential (redox), *in situ* chlorophyll fluorescence
- Lab: Sediment percent organic matter

On average, two or three vegetation morphotypes are sampled by fish and macroinvertebrate crews in each wetland, although four morphotypes are possible. The basic water quality sampling design is based primarily on the placement of three fyke nets within each major vegetation morphotype at a site. If fyke nets cannot be set in a morphotype, then macroinvertebrate sampling points are used instead as water quality sampling locations. Water quality data is then collected from fyke net or D-net locations as follows:

- Field: critical, recommended, and supplementary measurements are made at the first net set location within each vegetation morphotype. It is recommended that water quality measurements be made at each net set within the morphotype, but only one location is required.

- Lab: water is collected from each of the fyke net locations within a vegetation morphotype and combined to form a single composite sample, which is analyzed for critical and recommended water quality parameters.

BB2. Sampling Methods

Past experience sampling water quality in coastal wetlands suggests that, whenever possible, samples and *in situ* measurements should be made off the bow of the boat before any disturbance of the area to prevent contamination by suspended sediment. Substrate/sediment may be disturbed by the boat motor; crew exiting the boat; use of poles, paddles, or other items that touch the substrate; and uprooting of vegetation. Crew are trained on approaching each sampling point in a manner that avoids substrate disturbance, as well as how to recognize when substrate disturbance has occurred.

Field meters:

Water quality measurements using field instruments are made *in situ* at the mid-depth of the water column at a minimum of one location within a vegetation morphotype (i.e., the first fyke net location). Field instrumentation varies among sampling teams, but all groups will collect temperature, dissolved oxygen (concentration and percent saturation), pH, and specific electrical conductivity using sensors with specifications listed in Table BB4.1 below (e.g., Yellow Springs Instruments [YSI] 6600 or equivalent instrumentation). *In situ* measurements are taken at mid-depth with special care that substrates are not disturbed before readings are taken. pH may be measured using a multi-sensor YSI 6600 (or equivalent), or using a portable pH meter in water collected from the same depth for the water chemistry analyses described below. Turbidity may also be directly measured in the field if a field sensor is available, or it is determined using water collected for other analyses (see below). Supplementary measurements of oxidation-reduction potential (redox) and *in situ* chlorophyll fluorescence depend on the field instrumentation available to field crews. The specifications tabulated below for recommended and supplementary parameters (Table BB4.1) are standardized so that measurements are taken consistently among field crews.

Water sampling:

Water quality samples are taken from a single composite sample collected from the 3 fyke net locations (or 3 macroinvertebrate sample locations) within each vegetation morphotype. From each net location, water is collected by grab-sampling two-three successive 1-L samples from mid-depth using an acid-washed polyethylene bottle and pouring them into a 10-L polypropylene carboy. This is done using a 1-L poly bottle attached to an extension pole to dip water from shallow sites or in dense vegetation. In this manner, 6-9 L are collected from each

zone in which 3 fyke nets are set. Care is taken to ensure that no bottom sediment is collected. If bottom sediments are collected, the water is discarded, the carboy and sample bottles are thoroughly rinsed with surface water from the same zone, and the water collection process is started over in an area where the sediment has not been disturbed. In order to avoid potential errors due to larger pieces of detrital debris contaminating water samples, each water sample is poured through an acid-cleaned polypropylene funnel to which a 500 micrometer mesh screen is attached. Crews should collect enough water from each replicate to ensure sufficient water for all water quality samples listed below. The clearer the water, the more that is needed, up to 9 L total.

Composited water is then mixed by swirling the carboy and dispensed into a 4-L acid-cleaned polyethylene cubitainer for later processing (see below). The remaining water in the carboy is then re-mixed and used to determine secchi tube water clarity. Secchi tube clarity is measured against a light background with the tube shaded from direct sunlight (MPCA 2007, 2006; Anderson and Davic 2004). After this measurement is made, the remaining water is dumped from the carboy and the carboy is rinsed at least 3 times with surface water from the next vegetation morphotype and the water sampling and compositing process is repeated.

Bottles for specific analytes are rinsed with sample water before collection. All samples are stored in the dark, on ice, in the field and then processed further upon return to the lab or to the motel as soon as possible (no more than 12 hrs later). Preservatives should not be used in samples. See sample handling below.

BB3. Sample Handling and Custody

Water quality samples are labeled externally with labels that adhere to sample bottles even when wet. They are written on with black fine point Sharpie markers or similar markers that have been tested and proven to be waterproof. Labels consist of site ID, plant morphotype, replicate number, sample date, regional team initials, and crew chief name. Water quality samples in 4-L cubitainers are kept chilled on ice until they can be further processed in the evening. Samples are processed in the field or at the motel the same evening as follows, and in every case taking care to gently mix the water before aliquoting by inverting the cubitainer:

- Raw water: 2 x 250 mL poly bottles are filled with raw water; one is frozen as soon as possible for TN and TP (recommended), and the other is frozen as a back-up sample.

- Alkalinity titration: Alkalinity (required) is measured on an unfiltered portion of the sample as soon as possible after collection, but always within 12 hrs. Alkalinity is determined by titrating raw water samples with standardized sulfuric acid (APHA 2005, 2 end-point titration).

- Turbidity determination (required if not sent to a lab or measured in the field): two replicate subsamples of raw water are measured as per Table BB4.1 below.

- Filtration for chlorophyll-a: A measured amount of water, approximately 300-1000 mL, is filtered through a 47 or 42.5 mm Whatman GF/C glass fiber filter into an acid-cleaned, DI-water-rinsed filtration funnel and flask. The filter is used for chlorophyll-a extraction in the lab. The filter is carefully folded in half and then in half again with forceps, and then wrapped in aluminum foil with a label identifying it (site, zone, date, field crew, crew chief name, amount of water filtered). All chlorophyll "packets" are subsequently stored in a zip-lock bag that is then stored in a wide-mouth poly bottle that is iced and then frozen as soon as possible. Double-packaging ensures that meltwater does not affect the filters.

- Major ions color and chloride (recommended): 125-250 mL of the GF/C filtrate from the above filtration is refiltered through a 0.45 micrometer Millipore (or equivalent) membrane filter directly into a poly bottle and iced (not frozen) for later analysis of color and chloride or other major ions. (If sample is being shipped to a lab for processing, one chilled duplicate should be retained as a back-up). Process within 48 hours or as soon as possible.

- Filtration for dissolved nutrients (required; SRP, ammonium-N, and nitrate-nitrite N): Approximately 250 mL of GF/C filtrate from the above filtration is refiltered through a 0.45 micrometer Millipore (or equivalent) membrane filter directly into an acid-cleaned, DI-rinsed poly bottle via an acid-cleaned, DI-rinsed 60 mL polypropylene syringe fitted to a 24 mm filter holder or equivalent setup. The sample is initially iced and then frozen as soon as possible. (Again, if the sample is being shipped to a lab for processing, a frozen duplicate must be maintained by the regional laboratory).

Sample numbers and numbers of sample bottles are noted on field data sheets. Samples remain in the custody of field crews until they are delivered to the designated water quality laboratory either in person or via courier service. A chain-of-custody form accompanies the samples with a copy remaining with the field crew or regional laboratory, whichever initiates the shipment. At the laboratory, all sample codes are entered into the laboratory sample log-in book along with the date received and any notes regarding sample condition. This information is transferred to an electronic archival system maintained by each regional laboratory.

Regional laboratories not processing their own water quality samples ship frozen or appropriately preserved samples via courier in a cooler filled with dry ice if necessary. A list of samples and date of shipment is emailed to the receiving lab, which logs in the samples when received, and verifies receipt and condition of samples via email to the shipping lab. Results, including QA/QC data are provided via email to the regional team laboratory. The regional team laboratory retains frozen duplicates of all water samples as a backup against the loss of samples in shipping.

BB4. Analytical Methods Requirements

Water quality meter measurements (field): Water quality meters are inspected and calibrated on the required schedule for each parameter (see section BB7). In case of failure, field crews are trained in the standard procedures to follow that solve many cases of meter failure (see section A8). Crews also have the phone numbers of support staff to call for additional guidance and assistance. Crew leaders will explain all equipment failures and the implications of this for the data on the data sheets and transfer this information, along with appropriate error codes, to the database during data input. Table BB4.1 summarizes the field measurement parameter objectives, precision, accuracy, and method detection limits that are used for this program.

Water chemistry measurements (lab): Table BB4.1 also summarizes the analyte precision, accuracy, and method detection limits for each water chemistry analyte required or recommended for measurement either at the motel (i.e., alkalinity and possibly turbidity), or back at the main water quality laboratories. All laboratories participating in this program have confirmed that they can meet these standards. All parameters are measured within the listed holding times.

Each analytical measurement listed in Table BB4.2 specifies the water chemistry method to be used (with references), which represents the ultimate reference for participating laboratories. All methods and options for arriving at the required measurements and achieving the performance standards listed in Table BB4.1 are included in the references cited. These references are already owned by all of the participating water quality laboratories.

Sample disposal: Disposal of all wastes complies with federal, state, and local regulations governing waste management. The procedures written here meet these regulations. Disposal for samples of raw water (used for TN and TP) and filtered water (used for SRP, Ammonium-N, Nitrate/Nitrite-N, Chloride) is to rinse them down the drain to a wastewater treatment facility.

Raw water that has had its pH reduced, (e.g., for alkalinity titration) is neutralized, diluted and rinsed down the drain to a wastewater treatment facility.

Sample water (filtered or raw) that has been analyzed using a QAPP-approved method for TN, TP, SRP, Ammonium-N, Nitrate/Nitrite-N, or Chloride is collected with other instrument waste in hazardous waste containers which are routinely collected for disposal through each institution’s hazardous waste program.

Table BB4.1. Minimum performance standards for laboratory and field measurements that participating labs must achieve. See footnotes for explanation of measures.

Parameter	Precision*	Accuracy	Range‡	Method Detection Limit§	Limit of Quant.**	Units	Holding times
Ammonium-N	15%	10%†, 20%††	0.003 – 1	0.01	0.03	mg/L	28d
[Nitrate + Nitrite]–N by autoanalyzer or Nitrate-N by IC	15%	10%†, 20%††	0.003 – 1	0.01	0.03	mg/L	28d
Soluble reactive phosphorus (SRP)	15%	10%†, 20%††	0.002 – 1	0.005	0.015	mg/L	28d
Total Phosphorus (TP)	15%	10%†, 20%††	0.002 – 1	0.005	0.015	mg/L	28d
Total Nitrogen (TN)	15%	10%†, 20%††	0.01 – 2	0.01	0.03	mg/L	28d
Chlorophyll-a	15%	10%†	0.5 – 1000	0.5	1.5	µg/L	28d
Alkalinity	10%	10%†	0.5 – 1000	0.5	1.5	mg/L as $CaCO_3$	24h
Turbidity	10%	10%†	0.1 – 4000	0.1	0.3	NTU	2d
Color (dissolved)	10%	10%†	1 – 500	1	3	Color Units	2d
Chloride	10%	10%†, 20%††	0.03 – 1	0.1	0.3	mg/L	28d
Dissolved Oxygen	10%	10%†	0.1 – 20	0.1	0.3	mg/L	x
Specific conductivity (EC25)	10%	10%†	1 – 5000	1	3	µS/cm	x
pH[x]	0.1 units	0.1 units†	4 – 10	NA	NA	Std Units	24h
Temperature	0.1°C	NA	0 – 30	NA	NA	°C	x
Redox (ORP)	10 mV	10 mV†	-2000 to +2000 mV	1	1	mV	x
Secchi tube clarity	10%	NA	0 – 120	1	1	cm	x

*Calculated as Relative Percent Difference (%RPD)
†Calculated as %recovery of a known concentration in Quality Control Check Standards
††Calculated as %recovery of a known concentration in spiked matrix samples
‡ Approximate range of values that analytical method is capable of measuring
§ Calculated annually at each lab following methods in EPA 821-R-16-006
** Limit of Quantification (LOQ): Calculated as 3 * Method Detection Limit

Table BB4.2. Water quality procedures and analytical methods. SM refers to APHA (2005; *Standard Methods*)

Parameter	Procedure	Method Reference
Total Phosphorus (TP)	Persulfate digestion + SRP or Ion Chromatography	EPA 365.3; USGS (2003); Ameel *et al*. (1993, 1998); Dionex Method AN 254 SM 4500-P-J
Soluble Reactive Phosphorus (SRP)	Automated, Ascorbic acid or Ion Chromatography	SM 4500-P-E/F Dionex Method AN 254
Total Nitrogen (TN)	Persulfate digestion and NO_3+NO_2-N	USGS (2003); Ameel *et al.* (2003) SM 4500-P-J
Ammonium-N	Automated phenate (or salicylate) or Ion Chromatography	SM 4500-NH_3-G Or Dionex AN 141
Nitrate-N or Nitrate+Nitrite-N	Automated with cadmium reduction or Ion Chromatography	SM 4500-NO_3-C or SM 4500-NO_3- F
Alkalinity*	Titration (2 pt)	SM 2320 B
Chlorophyll-a	Spectrophotometric or fluorometric	SM 10200 H Axler and Owen (1994)
Chloride	Ion Chromatography	Dionex AN 141
Color (dissolved)	Spectrophotometric	SM 2120 C
Turbidity†	Nephelometric	USGS (2005)

*Usually measured at the motel the evening after sample is collected or in the lab for local sites
†Can be measured *in situ* with a meter or in the lab with a benchtop meter

BB5. Quality Control Requirements

Data Quality Objectives

Data quality objectives (DQOs) are qualitative or quantitative statements of:

- Precision (a measure of random error)
- Bias (a measure of systematic error)
- Accuracy
- Representativeness
- Completeness
- Comparability
- Sensitivity

Precision – Precision measures how much two or more data values are in agreement with each other. Precision is discussed in the introductory chapter of *Standard Methods for the Examination of Water and Wastewater,* 21st Edition, 2005. Field sampling precision is

determined by using field split samples or field duplicate samples. Water quality duplicates are taken at a minimum of 10% of sampled vegetation morphotypes or enough so that each crew generates a minimum of 3 duplicates per year, whichever is greater. Laboratory analytical precision is determined by comparing the results of split samples, duplicate samples, and duplicate spike samples.

Sampling and/or analytical precision are determined from split or duplicate samples by calculating the Relative Percent Difference (RPD) as follows:

$$RPD = (A - B) \div ((A + B) / 2) \times 100$$

where A is the larger of the two duplicate sample values and B is the smaller value.

Where three or more replicate samples or measurements have been taken, calculate the Relative Standard Deviation (RSD) instead of the RPD as follows:

$$RSD = (s/\chi) \times 100 \text{ (also called the CV, coefficient of variation)}$$

where **s** is the standard deviation of the replicate values and **χ** is the mean of the replicate values.

Accuracy – Accuracy is determined by calculating the recovery of a known addition (or spike) to samples and blanks, as well as recovery of Quality Control Check Standard (QCCS) solutions.

Recovery of known additions involves adding (or spiking) a sample or blank with a known amount of the analyte, and calculating the percent recovery of the spike. Spike concentrations are commonly 1 to 50 times the limit of detection for the analysis and fall within the linear range of the method. Concentrated solutions are used for spikes so that volume change in the sample is negligible. Recovery is expressed as a percentage and is calculated as follows:

$$\%\, recovery = \left[\frac{sample_{spiked} - sample_{unspiked}}{spike}\right] \times 100\%$$

where $sample_{spiked}$ and $sample_{unspiked}$ are the concentrations in the spiked and unspiked sample, respectively, and $spike$ is the known amount of the added spike. Acceptable limits for sample spikes are ± 20% in most cases (Table BB4.1).

Quality Control Check Standard (QCCS) solutions with a certified known concentration are analyzed with each batch of samples. QCCS solutions are analyzed at the beginning and end of each batch to evaluate drift during the analytical run. QCCS solutions are prepared to fall within the linear range of the method. Accuracy is evaluated by calculating the percent recovery as follows:

$$\%\, recovery = \left[\frac{concentration_{measured}}{concentration_{known}}\right] \times 100\%$$

where $concentration_{measured}$ and $concentration_{known}$ are the concentrations of the QCCS solution measured during the run and the certified known concentration, respectively. Acceptable limits for sample spikes are ± 10% in most cases (Table BB4.1).

Matrix spikes and/or QCCS will be analyzed at the rate of one every 20 samples or one per batch, whichever is less.

Bias – Bias is the systematic or persistent distortion of the measurement process so that the value given does not represent the true value. Field bias is assessed by use of field blanks and trip blanks. Adherence to proper sample handling, preservation, and holding time protocols helps minimize field bias. Since the sampling method for all sampling is grab sampling, field blanks (i.e., sampler blanks) are collected at least every 10 vegetation morphotypes sampled (every 3-4 sites). Most of the PIs and many field team leaders have conducted numerous research projects of this kind and their field collection and bottle preparation methods are well tested from previous state and federally (EPA) funded projects. They train and work with less experienced personnel. Laboratory bias is determined as part of the lab's internal quality control. Bias effects that fall outside the laboratory's acceptance limits are flagged.

Completeness – Expressed as the number of valid (usable) data points made to the total number of measurements expected according to the original sampling plan. Percent completeness is determined separately for each parameter and is calculated as follows:

% Completeness = (no. of usable data points ÷ no. of planned data points) x 100

Critical (e.g., required) water quality samples must be taken for a minimum of one suite of samples per fish or invertebrate vegetation morphotype sampled. Failure to obtain these samples due to meter malfunction, or any other variances from the established sampling protocol, should be thoroughly documented on field data sheets. Resulting data will also be qualified in the database to reflect these issues.

Representativeness – The degree to which data accurately and precisely represents parameter variations at a sampling point, or of a process or environmental condition. Representativeness of field data is dependent upon proper sampling program design and is maximized by following the sampling plan, using proper sampling protocols, and observing sample holding times.

Data are routinely screened for representativeness by comparing measured parameter values to historical data from this monitoring program and other sampling efforts and to current and historical data generated by other organizations, if available. In addition, program members rely on their limnological experience with other regional wetlands and streams to identify anomalies, should they occur.

Comparability – The level of confidence with which the program data can be compared to other data. Comparability of data is achieved by consistently following standard field and laboratory procedures and by using standard measurement units in reporting analytical data. Sample collection and handling techniques, matrix type, and analytical method are carried out according to standard analytical procedures and field sampling protocols. If quality control criteria (precision, accuracy, and representativeness) are known, data sets can be compared with confidence.

Sensitivity – For laboratory analyses, sensitivity represents the lowest level of analyte that can be reliably detected by the laboratory analytical method. *Method Detection Limit*s (MDLs) will be calculated once annually according to EPA 821-R-16-006. Note that most labs also conduct ongoing evaluation of the MDL throughout the year by adding data from each successive run to the MDL calculation in order to detect any significant changes to MDLs throughout the year. For the initial annual MDL calculation, a minimum of 7 blanks will be analyzed over the course of 3 days to incorporate any day-to-day variation resulting from lab operations (see EPA 821-R-16-006 and Water Quality SOP for additional details and calculations). The annual MDL will be entered into the project database by each lab for each water quality parameter for which an MDL is required. After the initial MDL study each year, ongoing MDL analysis throughout the year with additional data points should be used by regional labs to detect performance issues that require corrective action. These ongoing MDL studies will not be logged into the project database unless a significant change in workflow has occurred (new instrumentation, etc.).

As the MDL is approached, variance typically increases, which reduces the accuracy of measured values at these low levels. Therefore, a *Limit of Quantification (LOQ)* will also be determined as LOQ = MDL * 3.

QA/QC Specifics - Laboratory analytical and QA/QC protocols for determination of SRP, nitrate-N, ammonium-N, alkalinity, turbidity, TN, TP, chlorophyll-a, and color follow well-established methods (e.g., APHA 2005; USGS 2005). Participating laboratories are required to adhere to a QA/QC program that includes the following elements for each parameter measured: initial instrument calibration and subsequent calibration verification; initial and ongoing demonstration of analytical capability; method detection limit determination; analysis of field blanks, reagent blanks (or 'method blanks'), laboratory-fortified blanks (or 'matrix spikes'), and laboratory-fortified blank duplicates (or 'matrix spike duplicates'); estimates of precision and accuracy; and documented QC acceptance/rejection criteria. These requirements are satisfied by documentation of laboratory certification (State, Provincial, Federal or international body) as well as having a well-documented laboratory QA/QC program.

Compliance with the QA/QC program is coordinated and monitored by the laboratory's quality assurance officer or manager and must meet the minimum requirements outlined in this QAPP.

The stated objectives of the laboratory QA/QC program are to:

- ensure that all procedures are documented, including any changes in administrative and/or technical procedures
- ensure that all analytical procedures are conducted according to sound scientific principles and have been validated
- monitor the performance of the laboratory by a systematic inspection program and provide for corrective action as necessary
- ensure that all data are properly recorded and archived

All laboratory procedures are documented in writing as standard operating procedures (SOPs), which are edited and controlled by the participating laboratory. Internal quality control procedures are conducted by each laboratory in accordance with their standard operating procedures and the individual method requirements. Method-specific data quality objectives (performance standards) are found in Table BB4.1.

Data Qualifiers – Common data qualifiers will be used in this project. Values that are less than the MDL or between the MDL and LOQ will be flagged accordingly. On samples that require dilutions due to matrix interference, the MDL and LOQ will be elevated according to the dilution factor. Data points below LOQ will not be used in the calculation of laboratory precision. MS/MSD samples will be used for this purpose. Samples with values exceeding the upper range of a method on an initial run will be diluted and reanalyzed so they fall within calibration range.

Individuals Responsible For Water Quality QA/QC:

Western Great Lakes	Chris Filstrup/Valerie Brady
Central Great Lakes (US side)	Don Uzarski/Carl Ruetz/Ashley Moerke
Central Great Lakes (CA side)	Jan Ciborowski/Joseph Gathman
Eastern Great Lakes (US side)	Michael Chislock/Kathryn Amatangelo
Eastern Great Lakes (CA side)	Jan Ciborowski/Joseph Gathman/provincial-certified lab

Mid-Year QA/QC Checks:

Regional team leaders and co-PIs assess water quality sampling methods during each field season. In most cases, this is accomplished by traveling with field crews on at least one occasion per year. The program QA manager and assistant manager provide guidance for the checks, provide oversight on the checks, and receive the QC reports from team leaders/co-PIs.

Performance criteria will include:

- Appropriate sample bottle prep and labeling
- Appropriate contamination avoidance procedures, informed by field blank assessment
- Appropriate maintenance and calibration of water quality meters
- Appropriate documentation of meter maintenance and calibration
- Appropriate record keeping for data and samples

Note that separate mid-year QA/QC checks are not required for water quality laboratory analyses because each participating laboratory has a QA/QC program in place for the water quality parameters being measured. Most of the water quality labs in this program are certified (by a state, federal, or internationally recognized accreditation body). Such certification requires audits every 2 years and the routine running of proficiency test (quality control) standards, often multiple times per year, to ensure that machine output is within acceptance criteria (typically +/- 10%, but varies by analyte). Labs that are not state or federally certified at present are implementing yearly internal audits based on those done internally by state-certified labs. Adherence to these plans, which include method blanks, matrix spikes, and duplicates, ensures accurate and comparable data among participating institutions. Institutional laboratory QA/QC programs require re-analysis of samples (when possible) in cases when performance standards are not met. QC reports from the program laboratories are provided to the program QA managers in mid-winter.

BB6. Instrument/Equipment Testing, Inspection, and Maintenance Requirements

All field water quality and laboratory instruments are maintained in accordance with manufacturer's specifications and the requirements of the specific method employed. This maintenance is carried out on a regularly-scheduled basis and is documented in the laboratory instrument service logbook for each instrument. Emergency repair or scheduled manufacturer's maintenance will be provided under a repair and maintenance contract with factory representatives.

BB7. Instrument Calibration and Frequency

Field water quality meters are calibrated in accordance with manufacturer's specifications. Since a number of different instrument brands, models, and configurations are being used, only general calibration methodologies are provided here. Specific electrical conductivity, turbidity, redox (ORP), and pH are calibrated once per field trip (about every 10 days), while dissolved oxygen is calibrated daily. Field crews are required to certify on data entry sheets when meters were calibrated. Maintenance logs, including calibration frequency, are kept at each participating laboratory.

Specific conductivity: Sensors are calibrated using a 2-point method. Air is used to establish the zero point; a second point (i.e., the slope) is established using a purchased conductivity standard, generally 500 µS cm^{-1}. After entering the zero point, the sensor is rinsed with approximately 100 ml of high standard, the rinse solution is then discarded, and the probe is submerged in fresh standard. The instrument is then allowed to equilibrate before the high standard is entered and the calibration is completed.

Turbidity: Sensors are calibrated using a 2-point method. DI water is used as the zero point and a purchased turbidity standard, generally 40 NTU, is used for the slope. The sensor is rinsed thoroughly before calibration. Before adding the high standard, the sensor is rinsed with the high standard solution.

Redox: Sensors are calibrated using a single-point method with Zobell's solution. The solution supplier's instructions regarding temperature-correction of Zobell's solution are followed to ensure accurate calibration. There are multiple references that can be used when calibrating redox sensors and reporting values. The standard hydrogen electrode reference in which Zobell's solution has a redox value of +425 mV at 25°C is always used. The sensor is thoroughly rinsed with Zobell's solution prior to calibration. Zobell's solution is allowed to reach room temperature before calibration to reduce the amount of temperature-correction required.

Dissolved oxygen: Sensors are calibrated once daily using the saturated air method. Sensors are rinsed with clean water, blotted with a clean paper towel to dry, and placed in a damp calibration chamber. Calibration chambers should not be tightened onto the probe because this may increase the atmospheric pressure within the chamber and affect the calibration. Instruments are given sufficient time to stabilize and equilibrate before calibration. Manufacturer's instructions are followed to complete calibration. If barometric pressure is required as a calibration parameter, the pressure is acquired from a local weather station and entered as 'station pressure' not sea-level pressure.

pH: Sensors are calibrated using a 3-point method with purchased pH buffers of pH 4, 7, and 10. Buffers are prepared according to supplier's instructions and replaced when listed hold times expire. Sensor manufacturer's instructions are followed to calibrate pH sensors and sensors are rinsed with buffer prior to each calibration point. When possible, the sensor mV reading is logged in the sensor maintenance log. This raw sensor output can indicate when a sensor needs to be replaced according to manufacturer specifications.

BB8. Inspection/Acceptance Requirements for Supplies and Consumables

All sample containers for chemistry are acid-cleaned and DI-water rinsed as per APHA (2005), depending on the analytes being collected. Specifications for each batch of bottles are verified by checking the supplier's certification statement. Standards and reagents are assigned expiration dates based on vendor or method requirements. Materials that exceed the expiration dates are not used. Standards, reagents, and laboratory water is of sufficient purity to meet method and/or instrument manufacturer criteria. Each laboratory, as part of their respective QA program, designates individuals who are responsible for inspecting supplies and consumables, and for providing acceptance criteria. This information is retained in the program files.

BB9. Data Acquisition Requirements (non-direct measurements)

N/A

BC. Wetland Vegetation Sampling

Please refer to the CWMP vegetation sampling SOP for greater detail and step-by-step instructions, available on the CWMP website: https://www.greatlakeswetlands.org/Sampling-protocols.

BC1. Program Design

Upon arrival at the site, the field crew first determines whether or not the site is sampleable based on the following criteria: safe access, open connection to the lake or connecting channel, site is an emergent wetland, site still exists as a wetland and has not been destroyed by human disturbance (sites should still be sampled in this case if it is a benchmark site). If the site is rejected, the reason is recorded in the space provided on the field sheet. If sampleable, field crews draw on their aerial image maps of the site to indicate locations of vegetation patches and transects, if they are not using detailed maps provided to them.

The primary data collection at the site is the identification and quantification of all wetland plant species occurring in a specified number of sampling quadrats. Within wetlands, sampling occurs along three transects that run perpendicular to depth contours and that therefore cross the wetland vegetation zones present; the number of vegetation zones varies depending on each particular wetland. Operationally-defined vegetation zones are wet meadow, emergent vegetation, and submergent vegetation. If a distinct submergent zone is present, it is also sampled. Note that the vegetation sampling crews identify vegetation zones somewhat differently than do the fish and macroinvertebrate crews, who sample within vegetation morphotypes.

Transects can be no closer than 20 m to each other. In most wetlands, they are much further apart. The starting point of each transect is randomly-located along the upland or swamp forest edge (or the outer wetland edge if the crew arrives by boat), and the distance from this edge to the first quadrat sampling point is $1/6^{th}$ the width of the vegetation zone from the wetland edge. Vegetation is surveyed in 1-m^2 quadrats at regular intervals along transects, for a total of 45 quadrats per wetland (15 quadrats per vegetation zone). All survey quadrats are placed 2 m to the right of the transect line to avoid trampling effects. The length of the transect within a given plant zone is measured, and if the plant zone is greater than 11 m wide, the length of the zone is divided by 6 to determine the distance between the 5 sampling points in each zone on each transect.

If the vegetation zone is less than 11 m wide, a “narrow” sampling protocol is used. In this protocol, the field crew locates the midpoint of the narrow zone along the original transect. At this midpoint, an additional transect is placed perpendicular to the original transect. Survey plots along the perpendicular transect in the narrow zone are located at -8, -3, 2, 7, and 12 m

from the zone midpoint along the original transect. Narrow transects are most likely to be needed in either the wet meadow or submergent marsh zones.

In many coastal wetlands along the southern Great Lakes, invasive *Phragmites australis* has formed a dense monoculture more than 200 m wide. In these areas, sampling across this entire zone has greatly increased crew effort, reduced efficiency, and increased the likelihood of crew injury. To mitigate these issues without reducing data quality, sampling is conducted as needed within this zone at 5, 10, 15, 20, and 25 m from the *Phragmites* bed edge (either shoreward or lakeward edge, depending on accessibility), rather than spacing sampling points across the entire width of the zone. The actual width of the zone is calculated from the most recent year's Google Earth photos. Correlations between Google image interpretation and field surveys are high, and difficulty maintaining a straight transect line in *Phragmites* typically results in reduced accuracy from the field transects. Prior experience and data analysis show virtually no variability in vegetation composition within the *Phragmites* zone, indicating that there will be minimal loss of information by spatially restricting *Phragmites* sampling. When this modified protocol is used, it is referenced in the comment box and recorded in the database. The direction of entry into the *Phragmites* beds, either from the upland shoreline or from the water, is also noted.

A list of the most aggressive invasive plants was compiled for the Great Lakes Coastal Wetlands Monitoring Plan (GLCWC 2008), and a list of most upland and wetland invasive species in the Great Lakes region is found in Michigan's Floristic Quality Assessment program (Herman *et al.* 2001). New invasives are being added as they invade the Great Lakes. The Great Lakes Coastal Wetlands Monitoring Plan also contains a thorough list of plants encountered in coastal wetlands of all of the Great Lakes states, as recorded during inventories conducted with USEPA and USCZM funding from 1987 through 2004 (Albert *et al.* 1987, 1988, 1989; Minc 1997). Species lists from other relevant studies were added to the lists within the Great Lakes Coastal Wetlands Monitoring Plan prior to the initiation of program sampling. Taxonomic descriptions are cross-walked with the Flora of North America, which is available on-line (http://www.efloras.org/flora_page.aspx?flora_id=1). A new flora, *The Field Manual of Michigan Flora* (Voss and Reznicek 2012) from the University of Michigan Press, incorporates the most recent taxonomic treatments of the Flora of North America. However, local Great Lakes floras (Voss 1972, 1985, 1996) that are compatible with Michigan's FQA (Herman *et al.* 2001) are used for field identification to facilitate rapid sampling. Other floras that may prove helpful for identification of difficult wetland plants include Fassett (1957), Crow *et al.* (2006), and Gleason and Cronquist (1991).

BC2. Sampling Methods

Within each quadrat, all macrophyte species are identified to the lowest possible taxonomic unit (typically species). Representative specimens of plants that cannot be identified in the field are collected and preserved for identification in the laboratory. Some sterile or immature species, including grasses, sedges, and willows, cannot be identified to species, and while these

are noted as present, they cannot be used in the FQI analysis. Herbarium staff typically are not willing to identify sterile specimens, and thus sterile species are typically not curated. Almost all invasive exotic species can be recognized, even when sterile, and are included in the analysis. Percent cover for each plant species, total percent vegetation cover, and water depth (cm) is recorded for each quadrat.

Vegetation sampling data are considered critical for the majority of wetland sites (i.e., those not sampled only for birds and anurans). At least 90% of the quadrats must be successfully sampled to consider the site effectively complete and to use the data in subsequent analyses.

Support facilities for vegetation crews include a laboratory or make-shift washing facilities (e.g., tubs, buckets, and hoses in the motel parking lot) and plant presses for preserving plant specimens. The plant curation site is equipped with dissecting microscopes that magnify to 30x and at least the identification guides by Voss mentioned above.

Supplemental data collection. It is also recommended that percent cover of vegetation detritus or standing dead biomass be recorded for each vegetation quadrat – this is especially important for plots dominated by aggressive invasive plants. It is additionally recommended that supplemental information on depths of organic sediments, water clarity, and underlying mineral soil texture be collected at each vegetation plot. While these data are not required because they cannot be collected from every quadrat, fields to record the data are available on the field data sheets. Depths of organic soils (in centimeters) is measured by forcing a 10 ft (3 m) length of ¾ inch (1.8 cm) aluminum conduit or similar into the substrate until mineral soils are encountered. Water clarity is simply noted in terms important for vegetation: is the bottom visible or not? In highly turbid waters where the bottom is not visible, submergent and floating plants are typically absent. Mineral substrate is broken into classes that include 1) clay, 2) silt, 3) sand, 4) gravel, 5) pebble, 6) cobble, and 6) boulder, based on rapid field evaluation with the conduit probe and feeling the substrate with the fingers. Presence of two-storied soils, such as a thin veneer of sand over clay can also be noted in the comment field, and can be significant for understanding sediment dynamics within a wetland.

BC3. Sample Handling and Custody

A numbered label is attached to each unidentified plant and noted on the field form. Each sample is coded by site location, transect and plot number, and date to facilitate future entering of plant identities on the sample forms and in digital data files. These plants are placed in Ziploc bags for either identification in the laboratory or by herbarium staff. Plants requiring identification by herbarium staff are placed in a plant press for drying and storage. There are few difficult-to-identify rare plants in Great Lakes coastal wetlands, so unknown plants can be collected without jeopardizing rare or endangered species. Plants that resemble rare or endangered species will be photographed only.

Collected plants are placed in a cooler or refrigerator upon return from the wetland, in preparation for pressing within 24 hours. Pressed plants are dried either with heat or with a fan whenever possible. Plant samples are destroyed following identification, except for those of interest for the herbarium's collections, or samples kept as short-term identification aids to assist in training new personnel or as vouchers. A long term voucher collection is not being made as part of this program.

BC4. Analytical Methods Requirements

Performance criteria: Most specimens collected in the field are identified to the species level during the evening of collection using identification keys and a magnifying glass. Specimens not identifiable to species because of lack of characteristic features (flowers, fruits, etc.) are identified to the lowest taxonomic levels possible. Specimens of questionable identity are pressed and returned to the laboratory. If fertile, unknown and unusual specimens are sent to appropriate taxonomic experts for confirmation or refinement of taxonomic identity. Sterile or immature plants are identified when possible. Target turnaround time for plant identifications is 3 months after the end of sampling.

Macrophyte data includes a) identifying and quantifying invasive plants that are considered indicators of degraded habitat (Albert and Minc 2004), b) quantifying coverages of submergent and floating-leaved vegetation, and c) comparing local site mean Conservatism (mean C) values to regional mean C values (Herman et al. 2001).

One of the most difficult aspects of plant sampling in quadrats is accurate estimation of the percent cover of plant species present. Thus, indicator calculations use metrics that are not strongly dependent on accurate plant cover estimates, but instead during the final stage of analysis percent cover is converted to broad cover classes of 0-25%, 25-50%, 50-75%, or greater than 75% to calculate metrics. For both aggressive invasive species and submergent and floating plants that tolerate or respond to nutrient enrichment or sediment loading, these coarse cover classes are adequate for monitoring wetland quality changes.

Transect start and end points within vegetation zones are marked using GPS (e.g., waypoints created). This is required. Because quadrats are regularly-spaced within vegetation zones, quadrat points can be interpolated from start and end points. However it is recommended that crews take the time to create waypoints for all quadrats. In case of GPS equipment failure, the vegetation crew should borrow a GPS from the fish and invert crew to finish the site and inform their regional laboratory of the need for a replacement GPS unit. In cases when no GPS unit is available for replacement of failed equipment, start and end points of transects can be marked on printed areal photos of the site that all field crews have. Crew leaders should explain all equipment failures and the implications of this for the data on the data sheets and transfer this information, along with appropriate error codes, to the database during data input.

Several worksheets developed as part of the Great Lakes Coastal Wetlands Monitoring Plan are used to calculate macrophyte IBIs. These include 1) a table of wetland quality based on aquatic macrophyte sampling, 2) a flow chart for determining quality rating of submergent marsh zone or submergent component of an emergent marsh zone, 3) a table of species tolerant of nutrient enrichment, sedimentation, or increased turbidity, and 4) a combined standardized score based on 1-3 above (see Section D for further details on IBI calculations).

Software for the calculation of Conservatism coefficients and associated metrics are contained within the FQI software for Michigan (Herman *et al*. 2001). The Michigan FQI software has been used in prior Great-Lakes-wide coastal wetland plant sampling projects, and has been found to contain almost all wetland plants growing in the Great Lakes. One of the advantages of the use of the mean Conservatism scores in the FQI software is that it is based on the entire flora, not just a few indicator species. For this reason, the lack of a Conservatism score for one or two species at a site does not greatly alter the mean Conservatism scores.

Recent comparisons of IBI and Mean C scores from lower water conditions (2011- 2013) with recent high water conditions (2016-2019) showed little regional change in scores, although some individual marshes, especially in the highest-energy open lacustrine marshes, had major reductions in scores, but based on long-term observations these marshes will recover when water levels drop. Changes in Great Lakes water levels, as measured by USGS gauging station data, result in reduction of meadow and emergent plant diversity when water levels rise above long-term mean lake levels, often with a corresponding increase in submergent and floating plant diversity, but this does not in itself alter IBI or Mean C scores. The specific location of a given plant species or association of plant species will typically change with either an increase or decrease of water level, although this type of change is less for larger emergent vegetation, such as species of bulrush (*Schoenoplectus*), cattail (*Typha*), common reed (*Phragmites*), spikerush (*Eleocharis*), or bur-reed (*Sparganium*).

BC5. Quality Control Requirements

Precision: Precision refers to how similar duplicates or splits are to themselves and is calculated as a % difference: % difference = (A-B)/((A+B)/2) * 100. For vegetation samples, the ability to estimate precision is built into the sampling design with the large number of quadrat samples collected per site.

Accuracy: The systematic difference from a reference standard or an expert. This is assessed during the mid-year QC check (see below, this section).

Bias: Systematic bias by a crew or method. Bias is assessed during the mid-year QC check by observing transect and quadrat placement and percent cover estimates, and by cross-validating difficult-to-ID taxa that are preserved. The quadrat method of sampling makes detection of uncommon taxa less likely than some other methods, and may result in lower taxa counts than

other methods that cover more of the site (see sensitivity). This is a deliberate trade-off made to sample more sites rather than fewer sites more intensely.

Completeness: Calculated as % complete = (# useable sample pts)/(# planned pts) x 100. Sampling completeness is calculated for all sites; the target is 90% of target quadrats sampled.

Representativeness: How well sites were sampled is determined by plotting all sample points for each site on aerial photographs of the site and by checking the field sheets and database for problems, notes, and flags. This is done for all sites.

Comparability: Data comparability among crews within the program and to other non-project data is achieved by using standard, accepted methods; creating metadata explaining the methods; and having strict training and QA/QC for all crews and personnel.

Sensitivity: In this case sensitivity refers both to the lowest taxonomic levels achievable and to the ability to detect uncommon taxa. Identification depends on the life-stage of the plants and the condition of the plants, which is primarily controlled by the time of year of sampling. Our sampling is timed so that the most species are most identifiable when field crews are sampling. Uncommon taxa are not particularly detectable because of the small percentage of each site that can be sampled even with 45 quadrats. Again, this is a deliberate trade-off made to sample more sites rather than fewer sites more intensely.

QA/QC specifics: Members of the program team responsible for vegetation sampling receive rigorous taxonomic training prior to field sampling. Accurate plant identification is the most important component of vegetation monitoring. During the sampling season, representative specimens that cannot be identified in the field are returned to the laboratory for identification, with assistance from botanical experts when necessary (See section BC4 above). A collection of difficult-to-identify species is maintained to assist with future identifications. This is especially useful for commonly-encountered plants that are often found in non-flowering condition. The vegetation team maintains an ongoing dialogue to ensure accurate and consistent identifications.

Field teams ‘calibrate’ their percent cover estimates with each other during the yearly field training. Field teams seek concurrence with each other on percent cover estimates for each quadrat. Plant metrics are designed to be robust so that small errors in percent cover estimates do not result in wetland quality ranking errors. Re-measurement of quadrats at a site is conducted during training to calibrate individual sampler estimates of vegetation cover. The important test for this re-measurement is not the specific cover value estimates, but the final conversion of the cover values into the site metrics. The metrics are designed to be robust enough that small differences in individual plant cover values do not alter the metrics or the overall site quality ranking. Field team members confer with each other on percent cover

estimates for each quadrat; discrepancies in cover estimates exceeding 10% between individuals in a field team trigger a re-sampling of the quadrats in that vegetation zone.

Individuals Responsible For Vegetation QA/QC:

Western Great Lakes	Nick Danz
Central Great Lakes (US side)	Dennis Albert
Central Great Lakes (CA side)	Jan Ciborowski/Joseph Gathman
Eastern Great Lakes (US side)	Kathryn Amatangelo/Rachel Schultz
Eastern Great Lakes (CA side)	Giuseppe Fiorino/Ian Smith

Mid-Year QA/QC Checks:

Coverage estimates: Training and testing/certification for macrophyte cover estimation is conducted during the early summer training workshop. Additional mid-year QA/QC checks have also been implemented to ensure data quality. The program macrophyte experts (Dennis Albert, CMU; Nick Danz, UW-Superior; Rachel Schultz, SUNY Brockport) or other individuals whom they designate estimate percent cover in 5% of each participant's plots in real-time in the field with crew members. Deviations in cover estimates exceeding 10% will trigger re-sampling of the plot and additional corrective action (see section C1).

Species Identification: The program macrophyte experts (Dennis Albert, CMU; Nick Danz, UW-Superior; Rachel Schultz, SUNY Brockport) or other individuals whom they designate verify the identity of 90% of species (not samples or plots) identified by each participant who is working independently. The performance criteria for this QA/QC step is 90% accuracy of fertile plants or plants that can typically be identified in sterile condition (a list of these plants that do not fit these criteria is provided to field crews). This QA/QC step is based on a combination of field and laboratory identification. Preserved specimens or digital photographs are used as part of the identification process. This QA/QC evaluation occurs once per year during the sampling period. After verification, the macrophyte experts record the species identified correctly or incorrectly by each participant, which serves as a performance record for each participating individual. The macrophyte experts also distribute a list of particularly difficult taxa that require preservation and lab verification when they are encountered. Corrections are made to the macrophyte database when identification errors are found. Additional corrective actions are explained in section C1.

The program QA manager and assistant manager provide guidance during the checks, provide oversight on the checks, and receive the QC reports from the macrophyte experts.

BC6. Instrument/Equipment Testing, Inspection, and Maintenance Requirements

Dissecting scopes, used for plant identification, should be cleaned and inspected annually. Boat motors are also tuned up as necessary for safe operation. Crews carry at least one spare quadrat. Boat repairs are also often necessary. Most towns around the Great Lakes have boat repair shops, which can be used by field crews as necessary. Appropriate spare parts are carried

by crews for boats and trailers, such as spark plugs and appropriate wrenches, tire for the trailer, drain plug, fuel line, and sheer pins (if used). Spare batteries are carried for the GPS units and cameras. No other equipment used by the vegetation sampling crews requires equipment testing.

Water craft, trailers, and sampling gear are given rigorous disinfection to eliminate the transfer of nonnative and invasive species between sections of the Great Lakes (e.g., eastern vs. western Lake Erie, northern vs. southern Lake Michigan, etc.), and before moving between the lakes. Recommended disinfection includes washing the tow vehicle, boat, and trailer at a car wash, and hosing sampling equipment down with hot soapy water. Before leaving each boat ramp, boats should have their drain plugs removed, drain any water not being used for water quality sampling, and inspect the boat and trailer carefully for vegetation. Specific regulations for AIS decontamination of gear for each state are observed.

BC7. Instrument Calibration and Frequency
Recreational GPS accuracy (+/- 10 m) is sufficient for these data. GPS receivers are tested prior to and after the field season by taking repeated readings at a location visible on aerial photos, such as a parking lot with lines. Accuracy is assessed by plotting GPS waypoints on a georeferenced aerial photo of the test location (e.g., the parking lot). During the field season, field crews uploading GPS readings at least weekly. At least once per week, GPS points are plotted on aerial photographs of a sampled site and the image is presented to the field crew to verify that points appear to be within +/- 10 m of the actual sampling locations. All tests and results are logged and the logs kept with the appropriate GPS units.

BC8. Inspection/Acceptance Requirements for Supplies and Consumables
N/A

BC9. Data Acquisition Requirements (non-direct measurements)
N/A

BD. Macroinvertebrate Sampling

Please refer to the CWMP macroinvertebrate sampling SOP for greater detail and step-by-step instructions, available on the CWMP website: https://www.greatlakeswetlands.org/Sampling-protocols.

BD1. Program Design
Upon arrival at the site, the field crew first determines whether or not the site is sampleable based on the following criteria: safe access, open connection to the lake or connecting channel, site is sampleable (e.g., water depth is appropriate), site is an emergent marsh. If the site no longer appears to be a wetland, the crew should determine whether or not the site probably

was a wetland and has been destroyed by human influences, or if the polygon was actually in error and a wetland did not exist at the site in the recent past. If the site appears to have been a wetland that was destroyed (e.g., water too turbid for vegetation to grow, but substrate is appropriate; evidence of vegetation removal or dredging, etc.), then careful documentation of this wetland loss should be made on the datasheet and with pictures. If the site is rejected for sampling, the reason is recorded on the space provided on the field sheet and with pictures.

If the site is sampleable, additional general information about the site is collected by the crew as they conduct their sampling. This information includes information on the wetland shape, hydrologic connection to the lake, shoreline landuse, shoreline type (e.g., sand beach, riprap, etc), and types and amounts of disturbance visible to the crew (data fields and lists available on data sheets for crew to use). In addition, field crews draw on their aerial image maps of the site to indicate locations of vegetation morphotypes, any disturbances not visible on the aerial photos, and D-net sampling locations. Crew members for fish and invertebrates collaborate to collect this information and complete the field sheet and map.

Macroinvertebrate samples are collected from the major plant morphotypes in each wetland. Sampling begins in mid-June in the most southerly regions of the Great Lakes and continues into early September, moving north with the phenology of wetland plants and development of macroinvertebrate communities. This is the interval during which emergent plant communities generally achieve maximum annual biomass. In most cases, macroinvertebrates are sampled during the same sampling trips as fish. Therefore, this section makes references to the other sampling events to show how sampling is connected/coordinated. Note that there are some sites or plant morphotypes within a site that cannot be sampled for fish because of inappropriate depth, but that are sampleable for macroinvertebrates and water quality as well as the other data types.

Macroinvertebrate sampling is stratified by plant morphotype. Plant morphotypes are patches of vegetation in which a particular plant type or growth form dominates the plant community based on visual coverage estimates. Note that other species or growth forms will likely occur within a given plant morphotype; however, plant morphotypes should be near-monodominant stands that comprise at least 75% of the emergent or floating-leaved plant community. Plant morphotypes include *Typha* (cattail), *Nuphar-Nymphaea* (water lily, combined), *Schoenoplectus* (bulrush, include both dense and sparse areas where they occur; see below), *Peltandra-Sagittaria-Pontederia* (arrow-arum-arrowhead-pickerel weed, combined because of similar growth form), *Sparganium* (bur-reed), wet meadow (mixed vegetation, generally containing *Juncus* and *Eleocharis* with enough water to sample with D-nets), submersed aquatic vegetation (SAV), mixed emergent (not dominated by any one type of emergent vegetation), open water (special cases only, as outlined in section A8), and potentially other types such as floating bog mat. Note that *Schoenoplectus* morphotypes may need to be divided into sparse and dense sampling areas if the *Schoenoplectus* vegetation is more than 50-100 m wide. In these cases the outer (lakeward) edge of this plant stand may only support low stem density while more

shoreward zones are usually sheltered enough from wave action to support denser stands and a different macroinvertebrate community. Mixed emergent morphotypes may be sampled if they are a significant and conspicuous habitat type and there are not three other monodominant morphotypes to sample. Additional morphotypes may be identified upon consultation among all macroinvertebrate PIs. In this case, the QAPP, SOPs, and field sheets will be updated accordingly. Stratification by plant morphotype is required because GLCWP IBI metrics are formulated for specific plant morphotypes in order to be robust to water level fluctuations. The minimum depth required for sampling macroinvertebrates is 5 cm and the maximum depth is 2 m.

Plant morphotypes are identified by field crew leaders during site reconnaissance when the field crew reaches the site. The minimum area for plant morphotypes to be sampled for macroinvertebrates is approximately 400 m^2. This minimum patch size is based on keeping the sampling locations for replicate samples separated by at least 15 m. However, in cases where multiple, disjunct, smaller patches of the same vegetation type exist within a wetland, these smaller patches can each be sampled (1 or 2 replicates each) as long as the combined area exceeds approximately 400 m^2 and no patch is smaller than 25 m^2. If there are enough disjunct patches for a choice to be made by the field crew, the larger patches should be sampled.

Three replicate field-picked D-frame dip net samples are collected in each inundated plant morphotype to provide a truly representative sample of the macroinvertebrates occurring in this each morphotype. These replicates should be at least 15 m apart and should be associated with and adjacent to fish fyke net locations if fish are also being sampled in that morphotype. Spacing from one replicate sample location to the next (i.e., between sample 1 & 2 or 2 & 3) should not exceed 250 m in cases where the samples are collected in the same patch. The three sampling points are selected to represent the variability in the vegetation morphotype, and thus, likely, the variability in the macroinvertebrates living in this morphotype. In large vegetation stands, the three sampling points correspond with different shoreline features if they occur and if this can be done under the spacing constraints mentioned above. For example, in a large lacustrine wetland where the sparse *Schoenoplectus* morphotype extends along the shoreline lakeward of a cottage, a forested area, and a wet meadow, sampling locations are chosen to correspond with these different features. However, in many (or most) cases, a given vegetation morphotype does not cover enough area to be associated with different shoreline features, in which case sample locations are chosen to represent, to the degree possible, the variability of the vegetation morphotype itself. It is important to note that replicate sampling locations are being chosen to maximize variability, not minimize it as is often the objective with replicate sampling. The goal here is to capture as much of the variability in macroinvertebrate community structure as possible within the vegetation morphotype while adhering to the constraints of this sampling protocol.

GPS waypoints are made at each sampling point in each plant morphotype. Because macroinvertebrates, fish (when possible), and water quality are all sampled in each plant

morphotype, care must be taken that personnel doing the sampling do not interfere with one another or compromise the other sample types. Water quality data and water samples should be collected first at each location before any movement is made around the point. Past experience sampling water quality in coastal wetlands suggests that, whenever possible, samples and *in situ* measurements should be made off the bow of the boat before any disturbance of the area to prevent contamination and suspension of sediment. Substrate/sediment may be disturbed by the boat motor; crew exiting the boat; use of poles, paddles, or other items that touch the substrate; and uprooting of vegetation. Crew are trained on approaching each sampling point in a manner that avoids substrate disturbance, as well as how to recognize when substrate disturbance has occurred. After water quality sampling, macroinvertebrate sampling and fish net deployment may commence.

BD2. Sampling Methods

Macroinvertebrate samples are collected with standard 0.5-mm mesh, D-frame dip nets with openings approximately 30 cm wide by 16 cm tall in a D-shape. The sampling protocol detailed here yields qualitative macroinvertebrate samples that are used to calculate Index of Biotic Integrity scores. Note that two ways of 'semi-quantifying' sampling effort (counting dip net sweeps and timing of field picking) are included as meta-data, but are not intended to rigorously quantify sampling effort or macroinvertebrate density.

Each dip net replicate consists of a composite of sweeps. Each single "sweep" commences at the sediment surface, moves the net up through the water column while brushing through and against the vegetation and ends at the water's surface. This is one "sweep". Multiple sweeps are taken at a given point to incorporate all microhabitats and capture a good representative sample of the macroinvertebrates living in the detritus or sediment surface, on the plants, and in the water column. Care is taken not to collect excessive amounts of sediment or detritus, which makes field picking of organisms difficult.

To semi-quantify sampling effort, the number of net sweeps (i.e., 1 to 2-m passes) is counted and recorded on the sampling data sheet for each replicate sample. Counting of net sweeps is intended to provide a coarse measure of netting effort. After a series of net sweeps is made (and counted), the net will contain an assortment of invertebrates, detritus, and vegetation fragments. Net contents are then be emptied into white pans that are approximately 20 cm wide, 35 cm long and 5 cm deep (a recommended common pan size). This is an approximate size, and pan size can vary among crews because it is not critical to standardization of sampling. Organisms are picked systematically from discrete areas within each pan defined by 5x5-cm grid lines drawn on the inside bottom of sampling pans. This gridding ensures standardization of picking, rather than needing to standardize pan size.

Contents of the dip nets are distributed evenly across the pan prior to picking organisms. The person doing the netting continues to sample and fill the pan(s) until the pan(s) appear to hold a sufficient number of organisms for field picking to begin, at which time the number of net

sweeps is recorded on the data sheet. Though determining when to stop dip net sampling and begin field picking is arbitrary, field crews are trained in this during the pre-season training workshop. The number of dip net sweeps required depends on macroinvertebrate densities in each vegetation patch. For example, in patches replete with macroinvertebrates, only 5-10 net sweeps are required to fill pans sufficiently to allow the target number of organisms to be picked within the allotted time. In patches with sparse macroinvertebrate communities, many more sweeps will need to be made before picking can begin. The amount of vegetation and detritus deposited in pans varies based on characteristics of the site. However, excessive amounts of vegetation and detritus should not be collected because this significantly reduces picking efficiency. In cases where substantial amounts of detritus and vegetation are being collected in nets, a maximum of approximately 75% of the pan surface area should be covered, leaving at least 25% of the pan uncovered (white) in order to see the locations of grid lines. A small amount of water falls into pans with the net contents. Generally, this amount is a sufficient volume of water (2-5 mm depth in the pan) to facilitate picking of swimming organisms. Too much water in pans greatly reduces picking efficiency and should be avoided.

When possible, multiple individuals should work together to collect each replicate sample. When multiple individuals are working together on a single sample, they can either work from the same pan or work from separate pans, or a combination (e.g., 2 individuals working from one pan while one individual works from a different pan) and place organisms into a single vial for that sample replicate. The sampling protocol is robust to this type of variation because individuals will systematically focus on one small area at a time within each pan (i.e., a single grid square), which limits interference between individuals that are working from the same pan.

The target for each replicate is for 150 macroinvertebrates to be collected. Picking of individual replicates is timed using a stopwatch. If 150 organisms are picked before one-half-person-hour (i.e. two people for 15 minutes; three people for 10 minutes, etc.) elapses, then picking stops at 150 organisms and the number of person-minutes is recorded on the data sheet. If 150 organisms are not acquired within one-half-person-hour, the timer is stopped, organisms are tallied, and the running timer resumes as picking continues to the next multiple of 50, regardless of the time required to do so. For example, if after one-half-person-hour 115 organisms have been collected, picking will continue to 150, regardless of how long it takes to do so (and total elapsed time will be recorded). Therefore, each replicate sample should contain 50, 100, or 150 organisms. After each replicate sample is picked, the number of person-minutes required for collection and the number of organisms collected are both recorded.

Macroinvertebrates are picked from sampling pans using forceps and working systematically from one end of the pan to the other, attempting to pick all specimens from each square before moving on to the next. Special efforts should be made to ensure that small, cryptic and/or sessile organisms (those resting on or attached to vegetation or debris) are not overlooked within each grid square. However, microcrustacea (e.g., rotifers, cladocerans, ostracods, copepods) are not part of this protocol and should be ignored. Since the goal is for each

replicate sample to represent the relative abundances of macroinvertebrate taxa at each sampling location, picking bias must be minimized. Accordingly, the number of organisms remaining in each of the picked grids of the pan should nearly always be exhausted to the point where finding just a few more organisms requires a substantial effort. When this occurs, the next grid square is picked. If the entire pan is 'picked clean' before the target number of specimens is reached, then timing stops while dip nets are used to refill the pan(s). As noted above, multiple pans may be used to collect a single replicate sample as long as the grid method is used so that collected organisms represent the resident macroinvertebrate community.

Hand tally counters are used to keep track of how many organisms are collected. Specimens are immediately placed into labeled (site ID, plant zone, replicate number, sample date, regional team initials, and crew chief name) approximately 30-mL leak-proof vials containing 95% ethanol to ensure proper preservation. If glass sample vials are used, they must be stored in a manner that prevents breakage during transport.

Additional supplementary data that are collected with each macroinvertebrate replicate sample include (required): latitude/longitude via GPS waypoint, vegetation percent cover by growth form and cover type at both the water surface and sediment surface, organic substrate depth and mineral substrate texture. Note that the supplementary vegetation data are separate from the other vegetation sampling for the program and will be associated with macroinvertebrate and fish data only.

A 1-m^2 quadrat is used to determine surface and subsurface vegetation percent cover and as the location for the substrate assessment. In locations where both fish and macroinvertebrates are being sampled, the quadrat is placed 1 m to the right of the mid-point of the net lead when looking away from the net box. A ribbon or similar way of marking is used to identify the midpoint of each lead. In locations where fish are not being sampled, quadrats are placed roughly in the center of the area where dip net sweeps were made. To semi-randomize the specific location of quadrats when fish are not being sampled, quadrats are thrown over the individual's shoulder to reduce bias in sampling location.

Percent composition by growth form and cover type is estimated visually. Growth forms and cover estimated are the same as those for the vegetation morphotypes listed above. If species (or genera) within each growth form category are known, they are noted on the field data sheet. Although vegetation overlaps, crews are trained to standardize their quadrat percent cover estimates so that percentages sum to 100%; open water (surface) and bare substrate (bottom) are included to ensure that crews have quadrat coverages summing to 100%. Because percent cover can differ substantially from the surface to the bottom of a quadrat, percent cover is estimated separately for the quadrat when looking at just the water surface, and again when looking through the water column to the bottom of the quadrat. A picture is taken of

each vegetation quadrat in case there are questions later about vegetation type or percent cover.

Within the quadrat, the depth of organic substrate is determined by pushing a 2-cm diameter rod into the substrate until mineral substrates are reached. Note that this is not refusal depth, which is typically significantly deeper within surficial substrates. Placing the finger at this point of the substrate/water interface allows the rod to be withdrawn and the depth measured with a meter stick. In addition, the dominant and subdominant mineral substrate type is recorded. Mineral substrate texture is determined by feel using the categories and guidelines on the field data forms. Some labs analyze sediment organic matter as percent loss-on-ignition (%LOI). A core of substrate from the quadrat is collected for this purpose if the lab is doing that analysis. A sample size of about 100 mL of substrate is sufficient for analysis. The substrate from each replicate quadrat for a vegetation morphotype is homogenized in a container and only a subsample retained for lab processing (about 100 mL). Substrate samples are kept frozen until analysis. Full details are available in the invertebrate sampling SOP.

The same taxonomic keys are used by all labs for macroinvertebrate identification in the laboratory during the fall and winter. These are specified in the macroinvertebrate SOP and will be updated as new taxonomic keys are published. Each regional team laboratory maintains a reference set of preserved specimens that are used to train new staff and to compare with to ensure consistency in identifications. Standardized record keeping and sample archiving techniques are used to facilitate re-evaluation of taxonomy if taxonomic inconsistencies arise. Support facilities include a microscopy laboratory equipped with high-quality dissecting microscopes that magnify to 50x; access to nearby vent hoods for processing preserved samples; appropriate tools for manipulating invertebrates (fine-pointed forceps, needles, etc); and the taxonomic keys listed in the SOP.

Macroinvertebrate sampling data are considered critical for the majority of wetland sites (i.e., those not sampled only for birds and anurans) and must be 80% complete for each wetland site (80% of targeted samples are collected).

BD3. Sample Handling and Custody

Macroinvertebrate samples are labeled with both internal and external labels. External label types are those that have previously been checked for their ability to remain adhered to sample bottles even when wet. Labels will be written on with black fine point Sharpie markers or similar markers that have been tested and proven to be water-proof. Internal labels are made from waterproof paper and written on with either ethanol-proof ink or pencil. Labels include site code, plant morphotype, replicate number, sample date, regional team code, and crew chief name.

Samples remain in the custody of field crews for the duration of each field trip. At the laboratory, all sample information is entered in the laboratory log-in form, along with the date

received and any notes about sample condition. This information is transferred to an electronic sample processing spreadsheet maintained by each regional laboratory. This spreadsheet is updated as each sample is processed. Processed samples remain in the custody of the regional team laboratory. Invertebrate identifications are compiled on hard-copy laboratory sheets and then entered into the data management system. The hard-copy laboratory sheets are scanned as a back-up and stored at each regional laboratory.

Identified macroinvertebrates are stored for 5 years after collection, with alcohol preservative levels checked annually. All collections have metadata stored with the collection that decodes each site code into site name, state, county, lake, and latitude and longitude. The metadata also includes information about the program, the PI in charge of the collection, and where to locate more information. These metadata must be stored with the invertebrate collection as long as the collection remains in existence. After 5 years, or at any time if the PI or laboratory cannot keep the collection, the lead PI (Uzarski) and the other invertebrate co-PIs should be notified and offered the collection. Destruction of the collection should only be made with permission from the PI (Uzarski) and EPA GLNPO, and if no other co-PI is interested in maintaining it. To properly dispose of samples, ethanol should be drained into hazardous waste containers and disposed of following institutional hazardous waste procedures.

BD4. Analytical Methods Requirements

All sampling point locations are stored using GPS. In case of GPS equipment failure, the invertebrate crew will borrow a GPS from the vegetation crew to finish the site, if possible, and will notify their regional laboratory of the need for a replacement GPS unit. In the event that this is not possible, crews will mark each sample point on their field map. Failures of other equipment are dealt with in section BD6. Crew leaders will explain all equipment failures and the implications of this for the data on the data sheets and transfer this information, along with appropriate error codes, to the database during data input.

Performance criteria: Macroinvertebrates are identified to the lowest operational taxonomic unit necessary for IBI metric calculations (genus-level in most cases for insect taxa). A list of all macroinvertebrate groups and their targeted identification level has been provided to all identification laboratories. Labs that do not have the expertise to identify particular taxonomic groups are either provided with appropriate training (and certification) or they send those particular taxa to other program labs for identification by qualified individuals. Target turnaround time for macroinvertebrate identifications is 6-7 months after the end of sampling.

BD5. Quality Control Requirements

Precision: Precision refers to how similar duplicates or splits compare to themselves and is calculated as a % difference: % difference = (A-B)/((A+B)/2) * 100. The three replicate macroinvertebrate samples are collected within each vegetation morphotype. However, our goal with this sampling is to maximize rather than minimize variability to ensure that we are collecting the majority of types of aquatic invertebrates that inhabit each plant morphotype.

What is important for QC standards in this case is the precision with which field crews have captured the target number of macroinvertebrates for each replicate (50, 100, or 150 organisms). Thus, we compare field macroinvertebrate counts of each replicate to the number of invertebrates identified in the laboratory over the winter. If these numbers (number field-picked vs. number identified) differ by more than 25%, field data sheets will be checked for accuracy of field count and identifiers will make notes on probable causes for the discrepancy. If counts differ by >50%, macroinvertebrate PIs will examine these samples and determine whether or not data can be used.

Precision in the field should also pertain to similarity of sample collection by field crew members and similarity in picking of macroinvertebrates. In particular, new crew members must be trained to ignore microcrustacea and to only pick within their grid cell and not be distracted by moving invertebrates in other grid cells.

Accuracy: Accuracy is determined by difference from a reference standard or an expert. This is assessed by exchanging macroinvertebrate samples between adjacent identification laboratories. This QC exchange is done “blinded” so that the laboratory receiving a sample does not know the number or identity of the invertebrates in the sample. All discrepancies in identification are investigated and corrections made to data as appropriate. In addition, all discrepancies trigger retraining of identifiers. The target is at least 95% similarity in identifications across labs. Macroinvertebrate exchanges between adjacent labs are done yearly with this QC overseen by QC managers Brady and Cooper.

Bias: Systematic bias by a crew or method. Bias by crew members is be assessed during the mid-year QC check by observing sample collection and invertebrate picking (see mid-year QC check, below, this section). Systematic bias among crews is assessed during the lab exchange of samples. Because so little of a site can be sampled, only quite common taxa will be collected by this sampling method. This is a known bias with invertebrate sampling and has been written about extensively for stream sampling by Karr and Chu (1999).

Completeness: Calculated as % complete = (# useable sample pts)/(# planned pts) x 100. Sampling completeness is calculated for all plant morphotypes sampled. Each morphotype must have at least 2 replicates for the data from that morphotype to be included in the database.

Representativeness: How well sites were sampled is determined by plotting all sample points for each site on aerial photographs of the site and by checking the field sheets and database for problems notes and flags. This is done for all sites.

Comparability: Data comparability among crews within the program and to other non-project data is achieved by using standard, accepted methods; having metadata explaining the methods; having strict training and QA/QC for all crews and personnel; and by exchange of

samples among adjacent labs to determine accuracy, comparability, and potential bias in identifications (see Accuracy, above).

Sensitivity: In this case sensitivity refers both to the lowest taxonomic levels achievable, and to the ability to detect uncommon taxa. Identification depends on the life-stage of invertebrates and their condition after preservation. Life stage is primarily controlled by the time of year of sampling. Our sampling is timed so that the most taxa are identifiable when field crews are sampling. Crews are trained to minimize damage during preservation of organisms. Uncommon taxa are not likely to be detected because of the small area actually sampled for each site. Detection of uncommon taxa is not the goal of this monitoring program.

QA/QC specifics: All members of the program team responsible for invertebrate sampling and sample processing receive training and certification prior to field sampling (see section A8). Proper dip net sampling technique must be learned by all field crew members to prevent sampling bias (see section A8). Open dialogue within and among labs greatly reduces the need for corrective action. When taxonomic inconsistencies are discovered, team members with expertise are consulted. If they are unable to resolve the taxonomy, then regional or national experts are consulted. Team members working on invertebrate taxonomy use conference calls, webinars, and e-mail to share taxonomic information. After taxonomic issues are resolved, database queries are written to identify other samples that contain the questionable identifications, and those specimens are pulled and re-examined. Additional mid-year QA/QC checks also ensure each laboratory's macroinvertebrate data quality (below).

Individuals Responsible For Macroinvertebrate Sampling and Processing QA/QC:

Western Great Lakes	Valerie Brady/Holly Wellard Kelly
Central Great Lakes (US side)	Don Uzarski/Carl Ruetz/Ashley Moerke
Central Great Lakes (CA side)	Jan Ciborowski/Joseph Gathman
Eastern Great Lakes (US side)	Kathryn Amatangelo/Greg Lawrence
Eastern Great Lakes (CA side)	Jan Ciborowski/Joseph Gathman/Giuseppe Fiorino/Ian Smith

Mid-Year QA/QC Checks:

Macroinvertebrate field sampling: Regional team leaders and co-PIs assess macroinvertebrate sampling and picking bias by traveling with regional field crews at least once per field season to observe each crew member collecting and picking samples, and by inspection of the "remains" of each picking pan. Macroinvertebrate sampling performance criteria is assessed for each individual working on macroinvertebrate samples, and notes and scores on their performance rating become part of the permanent record for this program. The program QA manager and assistant manager provide guidance during the checks, provide oversight on the checks, and receive the QC reports from team leaders/co-PIs.

Performance criteria include:
- Correct D-net sweep procedure (satisfactory/unsatisfactory)
- Thoroughness of sampling of habitats (satisfactory/unsatisfactory)
- Efficiency and accuracy of picking (satisfactory/unsatisfactory)
- Accuracy of picking 'mobile' taxa (satisfactory/unsatisfactory)

'Mobile' taxa (e.g., amphipods) are those that are highly mobile and difficult to sample/capture. Corrective actions at the field crew-level are implemented if performance criteria are not met (see section C1).

Macroinvertebrate laboratory processing: Macroinvertebrate sample processing performance is assessed at the lab/institution level because past experience on similar projects has shown that invertebrate identification is most effectively accomplished using a team approach in which individuals specialize in certain taxonomic groups or specific elements of sample processing (initial sorting, family-level ID, genus-level ID). Mid-year QA/QC evaluations are accomplished by having laboratories exchange invertebrates from two vegetation zones with each other for blinded re-identification. Distribution of QA/QC samples across laboratories is coordinated by the program QA manager and/or assistant QA manager.

Performance criteria include:
- Percentage of taxa correctly identified to appropriate taxonomic level (95%)
- Proper sample preservation and labeling (100%)

Corrective action at the laboratory-level is implemented if performance criteria are not met (see section C1).

BD6. Instrument/Equipment Testing, Inspection, and Maintenance Requirements
D-frame nets are inspected before and after sample collection for holes or other damage. Damaged nets are repaired in the field, and replaced at the end of that sampling trip as necessary. Each crew carries one replacement net with them at all times. Crews also carry extra forceps. Boat and motor repairs are also often necessary. Most towns around the Great Lakes have boat repair shops, which will be used by field crews as necessary. Spare parts carried by crews include spark plugs and appropriate wrenches, a spare tire for the trailer, drain plug, fuel line, shear pins (if used), and a spare propeller shared among several crews working in the same region. Spare batteries are carried for the GPS units, cameras, and water quality meters.

Water craft, trailers, and sampling gear are subjected to rigorous disinfection to eliminate the transfer of nonnative and invasive species between sections of the Great Lakes (e.g., eastern vs. western Lake Erie, northern vs. southern Lake Michigan, etc. Rule of thumb = more than 150 miles between one site and the next), or before moving between lakes. Recommended disinfection includes taking the tow vehicle, boat and trailer to a car wash and hosing them and

the sampling equipment with hot soapy water. Use of Vircon Aquatic is also effective at killing many invasive species and is recommended for netting.

Most US states now require that, before leaving each boat ramp, boats should have their drain plugs removed, drain any water not being used for water quality sampling, and inspect the boat and trailer carefully for vegetation and other organisms. Some states (e.g., Minnesota) now require that all boats must be trailered with their drain plugs out. All state laws on AIS decontamination must be observed.

BD7. Instrument Calibration and Frequency
Microscopes are typically calibrated and aligned every 2-4 years, depending on scope type and manufacturers recommendations. Recreational GPS accuracy is sufficient for these data. GPS receivers are tested prior to and after the field season by taking repeated readings at known localities visible on aerial photographs. During the field season, field crews are uploading GPS readings nearly daily. At least once per week, GPS points are plotted on aerial photographs of a sampled site and the image is presented to the field crew to verify that points appear to be reasonably accurate. Accuracy during the field season is also checked *a posteriori* by comparing latitude/longitude at easily recognized localities (e.g., road stream crossings) with GPS readings. All tests and results are logged and the logs kept with the appropriate GPS units.

BD8. Inspection/Acceptance Requirements for Supplies and Consumables
N/A

BD9. Data Acquisition Requirements (non-direct measurements)
N/A

BE. Fish Sampling

Please refer to CWMP fish sampling SOP for greater detail and step-by-step instructions, available on the CWMP website: https://www.greatlakeswetlands.org/Sampling-protocols.

BE1. Program Design
Upon arrival at the site, the field crew first determines whether or not the site is sampleable based on the following criteria: safe access, open connection to the lake or connecting channel, site is an emergent wetland, site is sampleable (e.g., water depth is appropriate). If the site no longer appears to be a wetland, the crew should determine whether or not the site probably was a wetland and has been destroyed by human influences, or if the polygon was actually in error and a wetland did not exist at the site in the recent past. If the site appears to have been a wetland that was destroyed (e.g., water too turbid for vegetation to grow, but substrate is appropriate; evidence of vegetation removal or dredging, etc.), then careful documentation of

this wetland loss should be made on the datasheet and with pictures. If the site is rejected, the reason is recorded on the space provided on the field sheet and with pictures.

If the site is sampleable, additional general information about the site is collected by the crew as they conduct their sampling. This information includes information on the wetland shape, hydrologic connection to the lake, shoreline landuse, shoreline type (e.g., sand beach, riprap, etc.), and types and amounts of disturbance visible to the crew. In addition, field crews draw on their aerial image maps of the site to indicate locations of vegetation zones, any unshown disturbances, and fyke net set locations. Crew members for fish and macroinvertebrates collaborate to collect this information and complete the field sheet and map.

Fish are sampled from the major plant morphotypes in each wetland. Sampling begins in mid-June in the most southerly regions of the Great Lakes and continue into early September, moving north with the phenology of wetland plant development. This is the interval during which emergent plant communities generally achieve maximum annual biomass. In most cases, fish are sampled at the same time that macroinvertebrates are sampled. Therefore, this section duplicates portions of the macroinvertebrate section (BD), especially regarding plant morphotypes and net placement. Note that there are some sites or plant morphotypes within a site that cannot be sampled for fish because of inappropriate depth, but that are sampleable for macroinvertebrates and water quality as well as the other data categories.

Fish sampling is stratified by plant morphotype. Plant morphotypes are patches of vegetation in which a particular plant type or growth form dominates the plant community based on visual coverage estimates. Our sampling design is predicated on our previous data that show that which fish are found in wetland vegetation tends to vary by vegetation morphotype, plant density, and depth. Since depth also affects which plant species grow, this is a secondary consideration to vegetation morphotype. Thus, all fish sampling hinges on the dominant aquatic vegetation morphotypes found in a wetland. Note that other species or growth forms will likely occur within a given plant morphotype; however, the plant type should be near monodominant and comprise at least 75% of the emergent or floating-leaved plant community. Plant morphotypes include *Typha* (cattail), *Nuphar-Nyphaea* (water lily, combined), *Schoenoplectus* (bulrush, include both dense and sparse stands where they occur), *Peltandra-Sagittaria-Pontederia* (arrow-arum-arrowhead-pickerel weed, combined because of similar growth form), *Sparganium* (bur-reed), wet meadow (mixed vegetation, generally containing *Juncus* and *Eleocharis* if there is enough water to sample with fyke nets), submersed aquatic vegetation (SAV), mixed emergent vegetation (no dominant emergent plant type, but a mix of multiple emergent species), open water (special cases only, as outlined in section A8), and potentially other types such as floating bog mat. The mixed emergent plant morphotype may be sampled if it represents a significant and conspicuous habitat type and there are not three other monodominant morphotypes to sample. Additional morphotypes may be identified upon consultation among all fish PIs. In this case, the QAPP, SOPs, and field sheets will be updated

accordingly. Stratification by plant morphotype is required because GLCWP IBI metrics were formulated for specific plant morphotypes.

The original fish IBI of Uzarski *et al*. (2005) relied primarily on bulrush, water lily, and cattail-dominated morphotypes, and these morphotypes are sampled if present. *Schoenoplectus* stands are divided into or categorized as sparse and dense areas when the outer (lakeward) edge of this plant stand supports low stem density and the more shoreward zones, which are sheltered from wave action by the outer zone, support dense *Schoenoplectus*. In high lake-level years, inundated wet meadow may also be deep enough to sample with fyke nets. The minimum depth required for sampling fish is 20 cm and the maximum depth that will be sampled is 1.2 m. Therefore, plant morphotypes with depths ranging from approximately 5 cm to 20 cm are sampled for macroinvertebrates and water quality but not for fish.

Plant morphotypes are identified by field crew leaders once the field crew arrives at the site. The minimum area for plant morphotypes to be sampled is approximately 400 m^2. This minimum patch size criterion is designed to ensure that replicate nets are set no less than 20 m apart. However, in cases where multiple, disjunct, smaller patches of the same vegetation type exist within a wetland, these smaller patches can each be sampled (1 or 2 nets each) as long as the combined area exceeds approximately 400 m^2 and no patch is smaller than 100 m^2.

Three replicate fyke nets are set in each inundated plant morphotype to ensure good representation of fish using this morphotype. Replicates are traditionally taken to provide a measure of variability. But in this case replicates are also used to increase the amount of each plant morphotype's area that is sampled to better capture the diversity of fish species using that morhotype as habitat. Within each plant morphotype, each of the three replicate nets should be located at least 20 m from any other net to prevent the nets from interfering with one another. Spacing from one net to the next (i.e., between net 1 & 2 or 2 & 3) should not exceed 150 m in cases where the nets are set in the same patch. Note that macroinvertebrate sampling locations are associated with and adjacent to fyke net locations. Water quality is also sampled in each plant morphotype.

The three fyke net locations are selected to represent, to the degree possible, the variability in the plant zone. In large plant morphotypes, the three sampling points should correspond with different shoreline features if they occur and if this can be done under the spacing constraints mentioned above. For example, in a large fringing wetland where a sparse *Schoenoplectus* stand extends along the shoreline lakeward of a cottage, a forested area, and a wet meadow, sampling locations are chosen to correspond with these different features. However, in many cases, a given vegetation morphotype does not cover enough area to be associated with different shoreline features, in which case sample locations are chosen to represent, to the degree possible, the variability of the morphotype itself, which increases the likelihood of representing variability in the fish assemblage of this habitat. GPS waypoints are created for each fyke net location.

Because macroinvertebrates, fish, and water quality are sampled in each plant morphotype, care must be taken so that activities of personnel engaged in one type of sampling do not interfere with one another or compromise the other samples. Water quality data and water samples are collected first at each location before any movement is made around the point. Past experience sampling water quality in coastal wetlands suggests that, whenever possible, samples and *in situ* measurements should be made off the bow of the boat before any disturbance of the area to prevent contamination and suspension of sediment. Substrate/sediment may be disturbed by the boat motor; crew exiting the boat; use of poles, paddles, or other items that touch the substrate; and uprooting of vegetation. Crew are trained to approach each sampling point in a manner that avoids substrate disturbance, as well as how to recognize when substrate disturbance has occurred. Water quality data and water samples are typically collected from the bow of the boat before anyone enters the water and with the engine off. After water quality sampling has been completed, macroinvertebrate sampling and fish net deployment can commence.

Fish communities are passively sampled using fyke (i.e., trap) nets deployed overnight. At each wetland, three fyke nets are deployed in each fishable plant morphotype. A 'fishable' plant morphotype is one of the plant morphotype or types described above with water depth between 20 and 120 cm. Shallower water cannot be effectively fished with the fyke nets using GLCWP methods.

The fyke nets used by all crews conform to these specifications:

Large nets

Lead:

-25' x 3' (± 1 ft x 3 inches)
-3/16" mesh (exact match required)
-weighted line on bottom
-floats on top
-loops on top and bottom of each end for poles or similar strategy

Trap:

-4' x 3' frames (2 frames, size ± 6 inches x 3 inches, approximately 3' apart)
-3/16" mesh (exact match required)
-1st hoop approximately 3' from second box
-hoops approximately 1.5' apart
-hoops diameter 30" (± 3 inches)
-5 hoops
-funnels on 1st and 3rd hoops
-funnel hole inside diameter 6-1/2" (± 1 inch)
-wings 6' long, 3/16" mesh (exact match required on mesh size)

Small nets

Lead

-25’ x 1.5’ (± 1 ft x 3 inches)
-3/16” mesh (exact match required)
- weighted line on bottom
-floats on top
-loops on top and bottom of each end for poles (or similar strategy)

Trap:

- 3’ x 18” (2 frames, size ± 4 inches x 2 inches, approximately 18” apart)
-3/16” mesh (exact match required)
-1st hoop approximately 18” from back box
-hoops approximately 12” apart
-hoop diameter 12” (± 3 inches)
-5 hoops - 2 funnels
-funnels on 1st and 3rd hoops
-funnel hole inside diameter 4” (± 1 inch)
-wings 6’ long, 3/16” mesh (exact match required on mesh size)

BE2. Sampling Methods

Fish sampling is conducted using three replicate fyke nets in each plant morphotype for one net-night (Uzarski *et al*. 2005, Brady *et al.* 2007). The timing of sampling should correspond to the phenology and relative maturity of the vegetation in each system (crews will work from south to north). The method of determining locations at which to set nets is described above, and locations will correspond to places where macroinvertebrates and water quality are sampled and water is deep enough. Sampling will be completed by mid-September as seasonal movements of fish to winter locations may bias estimates of community composition.

Two sizes of fyke nets are used (see required and recommended specifications above). Smaller nets should be set in water approximately 20 - 50 cm deep; larger nets are set in water depths of 50 – 120 cm. The depth of water in each plant stand dictates net size used since the main difference between large and small nets is height. Nets are placed with the mouth opening perpendicular to the vegetation stand of interest, with leads extending from the center of the mouth of the net into the vegetation. The goal is to catch fishes that are using (inside) the plant morphotype, rather than those moving along the edges of the plant morphotype. Wings should be set at 45° angles to the lead and connected to the outer opening on each side of the net, when possible. In very large plant morphotypes where setting the trap outside of the patch is not possible, nets should be set with the lead pointing toward shore. In dense stands of vegetation where the wings cannot be set at 45 degree angles (e.g., cattail, *Phragmites*), wings should be set at 90 degree angles or so as to block fish that are swimming along the edge of the morphotype from entering the net so that only fish from within the morphotype are captured. Nets should be set so that the top of the cod end is above the water surface to prevent turtles and other air-breathing vertebrates from drowning.

Nets are set for one night (at least 12 hr), after which time they are emptied. The trapped fish are identified to species, counted, measured, and released alive. The times of net deployment and recovery are recorded on field data sheets. A minimum of 25 individuals per species and age category (2 categories: young-of-year [YOY] vs. older [i.e., not YOY]) are measured to the nearest mm (total length). When individuals are counted, separate tallies are made for YOY vs. older individuals of each species. Fish less than 20 mm in length are not counted because the sampling gear does not accurately capture fish this small. All fish are handled following university wildlife use and care guidelines, and an approved program-specific plan is in place at each regional laboratory before sampling begins each year. Appropriate state and provincial permits are also obtained before sampling begins.

All crews have photo keys of Great Lakes fish species, including their key taxonomic characteristics, developed previously by Uzarski *et al.* (for GLCWC) and Brady *et al.* (for GLEI). If a fish cannot be identified in the field, representative specimens (small fish) or high-quality digital photographs (medium size and large fish) are returned to the laboratory for identification, with assistance from experts when necessary. Photographs are used for medium size and large fish or where collection of fish samples is not permitted by law or regulation. When digital images are used, the putative species name (if known), total length, site ID, plant morphotype, date, regional team code, and crew leader's name will be included in the image. Additional photographs of key features are taken to aid identification of unknown specimens. These pictures are uploaded to the database as a record of identification. Each fish sampling crew maintains a reference set of preserved specimens (fixed in 10% buffered formalin and then transferred to 70% ethanol for storage) in their laboratory if allowed by state, provincial, or federal regulations. When species are encountered that are not part of the lab's collection, a voucher specimen should be collected and preserved, if allowed. For large specimens (>20 cm), or where collection of fish specimens is not allowed, fully documented digital photographs will be collected instead of specimens. As with the other indicators, ongoing dialogue among program partners ensures consistent taxonomy and minimizes the need for corrective actions.

Fish samples are considered critical for targeted wetland sites (i.e., those not selected for bird and anuran sampling only). However, occasionally nets are knocked down by waves, vandalized, or damaged by turtles or mammals. If 2 of the 3 nets in a plant morphotype are determined by the field crew leader not to have representatively sampled the plant morphotype for these or other reasons, the nets will be re-set for a second night. The senior field crew leader and/or the regional team leader should be consulted on this decision. If the fishing integrity of nets is not maintained for at least 2 of the 3 nets for a second night, the regional team leader must be consulted about whether to reset nets or move to the next site. In addition, if fewer than 10 fish are collected in total from all 3 nets within a plant morphotype, the nets will be re-set for an additional night. Prior to deployment, all nets must be inspected for holes or other damage and repaired as necessary. Significant net repairs may need to be done by a net company.

Fish sampling crews need relatively little in the way of support facilities. Needs include a laboratory with nearby vent hoods for handling preservative. The laboratory should be equipped with dissecting microscopes that magnify to 20x and appropriate guides for Great Lakes fish (e.g., Bailey *et al.* 2004, Hubbs *et al.* 2004, Corkum 2010). Fish crews need a minimum of 3 of each size of the nets specified above, and 6 of each size is recommended. Also required are a boat, trailer, and towing vehicle.

BE3. Sample Handling and Custody

Fish that cannot be identified in the field are preserved or photographed for laboratory identification, depending on fish size and state, provincial, and federal regulations. Fish are humanely euthanized following university animal use protocols for wild animal specimens. Specimens are initially fixed in 10% buffered formalin in plastic containers labeled with both internal and external water- and preservative-proof labels (site ID, plant morphotype, fyke net number, unknown fish ID number, regional team code, and field crew leader name). Whenever unidentified fish specimens are kept or photographed, a note is made on the field data sheets that includes the sample number (if preserved) or photograph number. Samples remain in the custody of field crews for the duration of each field trip. At the laboratory, unidentified fish specimens are entered into the laboratory log-in sheet, along with the date received and any notes about sample condition. At this point, fish can be placed in 70% ethanol as long as they have been fixed in formalin for at least 2 days.

Preserved fish or their photographs will be stored for up to 5 years after collection in case there are further questions about proper identification. Photographs of fish used for identification are also uploaded into the data management system to allow for later verification by other fish experts and provide a record of identification. If a specimen is donated or lent to a museum because of its taxonomic or distributional value, records of its disposition are kept by the regional laboratory and entered into the database. All collections are stored with the collection metadata that decodes each site code into site name, state, county, lake, and latitude and longitude. The metadata also include information about the program, the PI in charge of the collection, and where to locate more information. This metadata must be stored with the fish collection as long as the collection remains in existence. After 5 years, or at any time if the PI or laboratory cannot keep the collection, the lead PI (Uzarski) and the other fish co-PIs should be notified and offered the collection. Destruction of the collection should only be made with permission from PI (Uzarski) and the EPA GLNPO, and if no other co-PI is interested in maintaining it.

BE4. Analytical Methods Requirements

All fish net sample locations are saved as waypoints using recreational GPS. In case of GPS equipment failure, the fish crew should borrow a GPS from the vegetation crew to finish the site, if possible, and inform their regional laboratory of the need for a replacement GPS unit. If this is not possible, crews will carefully mark the location of fyke net sets on their paper field maps. Other equipment failures are dealt with in section BE6. Crew leaders explain all

equipment failures and the implications of this for the data on the data sheets and transfer this information, along with appropriate error codes, to the database during data input.

Performance criteria: Fish are identified to species, although it may not be possible to identify some very young specimens. Fish smaller than 20 mm total length are not counted or identified because fish this small are not accurately sampled by nets of our mesh size. All regional laboratories have qualified personnel who can identify Great Lakes fish to species. Target turnaround time on preserved difficult identifications is two months after the end of sampling.

BE5. Quality Control Requirements

Precision: Precision refers to how similar duplicates or splits are to themselves and is calculated as a % difference: % difference = (A-B)/((A+B)/2) * 100. The three nets set per vegetation zone at each site are used to try to capture a good representative sample of the species using the plant morphotype and are not expected to be duplicates of each other. It should be noted that variability among samples, even within the same morphotype, is expected to be relatively high due to the high natural variability of fish assemblages using these habitats. However, to maintain continuity of effort, fish net replicates should be set for relatively similar amounts of time. Any nets whose set time (time fished) is more than 50% greater or less than the other nets for that plant morphotype should not be used (i.e., data discarded). In addition, at least 2 replicate nets must be considered to have “fished” for each plant morphotype for the fish data from that morphotype to be considered valid for use and data entry.

Accuracy: The systematic difference from a reference standard or an expert. This refers to both the accuracy of fish identification and the accuracy and correctness of net placements. Both will be assessed during the mid-year QC check (see below, this section). Identification of fish is expected to be 100% for a combination of: 1) identifying commonly-encountered Great Lakes fish old enough to identify and 2) knowing when to preserve or photograph fish whose identity cannot be confirmed in the field. Failure to achieve 100% means that the person cannot identify fish by themselves and must have all of their identifications checked by someone who has passed these tests. Every crew pulling nets must include at least one person who is at this level (most crews have several members at this level). Correctness of net placement is also expected to achieve 100% accuracy. This is a crew test as less experienced members will continually be encountering new situations and will need to rely on the expertise of more experienced crew. Crews that have no experienced members must text photos of the net sets at their first few sites to their team leader or crew chief for a second opinion until they achieve 100% approval on sets in 3 morphotypes.

Bias: Systematic bias by a crew or method. Bias will be assessed during the mid-year QC check by observing net placement and fish species ID (see mid-year QC check, below, this section). Fish are mobile, which means that a few nets can sample more of a site. However, fish can also detect the nets and may avoid entering them. This is a known bias incorporated into the protocol (all gear types have biases for or against various types of fish), and has been studied

fairly well (Murphy and Willis 1996; Ruetz *et al.* 2007). Bias in net placement must also be guarded against and will be checked by the regional PI during the mid-season QC check.

Completeness: Calculated as % complete = (# useable sample pts)/(# planned pts) x 100. Sampling completeness will be calculated for all plant morphotypes sampled. At least 2 of the 3 nets set for each morphotype must be considered to have "fished" (see criteria above) for the data for this morphotype to be considered valid and entered into the database. Some morphotypes contain very few fish because of their water chemistry (low dissolved oxygen) or plant structure. If after two attempts (2 nights of net sets), too few fish have been caught in nets for valid sets, the regional PI must be consulted by the team to determine if the issue is with the sets (the crew) or the type of habitat (in which case, not finding many fish is the true condition of this habitat type).

Representativeness: How well sites were sampled will be determined by plotting all sample points for each site on aerial photographs of the site and by checking the field sheets and database for problems notes and flags. The number of nets that "fished" (stayed upright and intact) will be calculated. All these will be done for all sites and plant morphotypes.

Comparability: Data comparability among crews within the program and to other non-project data will be achieved by using standard, accepted methods; creating metadata explaining the methods; and having strict training and QA/QC for all crews and personnel.

Sensitivity: In this case sensitivity refers both to the lowest taxonomic levels achievable, and to the ability to detect uncommon taxa. Identification will depend on the particular taxa and age of fish. Taxa types that are known to be difficult to identify (e.g., shiners) will be recommended for routine preservation. Uncommon taxa may not be detectable because of the low percentage of each site that can be sampled. In addition, some fish will avoid the nets (see bias). The fish IBIs were created to be robust to these issues.

QA/QC specifics: Damaged nets or sets determined to be tampered with or unproductive by field personnel (for example, due to a collapse or substantial holes) should be re-set for a second night (see above). Because fishes are primarily identified in the field, it is essential that all members of the program team who are sampling fish are proficient in fish identification. Therefore, all individuals working independently on fish sampling are trained, tested, and certified prior to sampling (see Section A8). Additional QA/QC checks as well as laboratory reference collections of preserved specimens or photographs ensure data quality. Reference collections are maintained by each laboratory that is independently collecting fish data. Voucher specimens for each observed species are preserved in 10% buffered formalin and then transferred to 70% ethanol for the duration of the program. For species in which observed specimens exceed 20 cm, fully documented digital images stored in multiple locations (including the database) are sufficient to verify identifications. When digital images are used to

verify species identity, the species name, location, date, regional team code, and field crew leader's name must be written on a white background and made clearly visible in the image.

Individuals Responsible For Fish Sampling QA/QC:

Western Great Lakes	Josh Dumke/Valerie Brady
Central Great Lakes (US side)	Don Uzarski/Carl Ruetz/Ashley Moerke
Central Great Lakes (CA side)	Jan Ciborowski/Joseph Gathman
Eastern Great Lakes (US side)	Matt Altenritter/Kathryn Amatangelo
Eastern Great Lakes (CA side)	Giuseppe Fiorino/Ian Smith

Mid-Year QA/QC Checks:

Regional team leaders or co-PIs will annually assess fish data quality for crews collecting fish data. Whenever possible, evaluations will be made both in the field and on the laboratory's reference collection. Mid-year field QA/QC evaluations will be conducted at the crew level since fish identification is generally done as a team (individuals only identify species about which they are confident and either pass the fish to another team member or preserve/photograph the specimen for laboratory identification), but the person doing the QC check will note which crew members are not proficient at identifying fish and confirm with the crew leader that the identifications made by these individuals are always double-checked. The program QA manager and assistant manager provide guidance during the checks, provide oversight on the checks, and receive the QC reports from team leaders/co-PIs.

Performance criteria will include:
- Correct identification of plant zones for setting nets (satisfactory/unsatisfactory; 100%)
- Correct setting of fyke nets (satisfactory/unsatisfactory; 100%)
- Accuracy of species-level IDs in the field/laboratory (95% for individuals; 100% for team)
- Proper handling of live fish (100%)
- Determination of when to retain specimens for laboratory ID (100%)

Failure to meet performance criteria will trigger corrective action (see section C1).

BE6. Instrument/Equipment Testing, Inspection, and Maintenance Requirements

Fyke nets are examined for holes and defects before and after each net set. The occurrence of holes that might have compromised net integrity during a set are noted on field sheets, and if such holes were substantial and affect 2 or more nets per vegetation morphotype, the nets are repaired and re-set. Crews carry net repair kits with them and repair nets in the field whenever possible. Major repairs may require the assistance of a net-making company. Boat or motor repairs are also often necessary. Most towns around the Great Lakes have boat repair shops, which are used by field crews as necessary. Spare parts carried by crews include spark plugs and appropriate wrenches, a spare tire for the trailer, drain plug, fuel line, sheer pins (if used), and a

spare propeller shared among several crews working in the same region. Spare batteries are carried for the GPS units, cameras, and water quality meters.

To prevent the spread of invasive species, including disease, boats and trailers are drained and inspected upon haul-out while still at the boat launch. Watercraft, trailers, and sampling gear undergo rigorous disinfection to eliminate the transfer of nonnative or invasive species between sections of the Great Lakes (e.g., eastern vs. western Lake Erie, northern vs. southern Lake Michigan, etc. Rule of thumb = more than 150 miles between one site and the next triggers disinfection protocols), or before moving between lakes. Recommended disinfection includes taking the tow vehicle, boat, and trailer to a car wash, and hosing them and the sampling equipment down with hot soapy water. Vircon Aquatic is also effective at killing many invasive species and is recommended for netting. No water will be transferred from one Great Lake or section of a Great Lake to another section or to an inland lake or water body.

Most US Great Lakes states now require that, before leaving each boat ramp, boats should have their drain plugs removed, drain any water not being used for water quality sampling, and inspect the boat and trailer carefully for vegetation and other organisms. Some states (e.g., Minnesota) now require that all boats must be trailered with their drain plugs out on penalty of fines for violators. All state AIS decontamination requirements must be followed.

BE7. Instrument Calibration and Frequency
Recreational GPS accuracy (+/- 10 m) is sufficient for these data. GPS receivers are tested prior to and after the field season by taking repeated readings at a location visible on aerial photos, such as a parking lot with lines. Accuracy is assessed by plotting GPS waypoints on a georeferenced aerial photo of the test location (e.g., the parking lot). During the field season, field crews upload GPS readings at least weekly. At least once per week, GPS points are plotted on aerial photographs of a sampled site and the image is presented to the field crew to verify that points appear to be within +/- 10 m of the actual sampling locations. All tests and results are logged and the logs kept with the appropriate GPS units.

BE8. Inspection/Acceptance Requirements for Supplies and Consumables
N/A

BE9. Data Acquisition Requirements (non-direct measurements)
N/A

BF. Bird and Anuran Sampling

BF1. Program Design
Over the past thirty years considerable field data have been gathered and analyzed to develop anuran and bird monitoring protocols in the Great Lakes region, especially in wetlands (Niemi

1980; Hanowski *et al.* 1990, 2007a,b; Gibbs and Melvin 1993; Howe *et al.* 1998, 2007; Weeber and Valliantos 2000; Price *et al.* 2004, 2007; Meyer 2006; Crewe and Timmermans 2005; Etterson *et al.* 2009). The terminology of "anuran" replaced "amphibian" in 2017 to more accurately reflect that we are primarily sampling frogs and toads that vocalize. Other amphibians such as salamanders are not being sampled. This program has been built on existing work by 1) establishing a strategic baseline of site-specific data and 2) articulating and validating a clear, scientifically rigorous plan for long term monitoring of bird and anuran populations in Great Lakes coastal wetlands. The field component of this monitoring program was built on protocols contained in the GLCWC Monitoring Plan (with the exception of certain modifications described in this document), but additional data have been collected to improve the protocols, if necessary, and to insure compatibility with the existing volunteer Marsh Monitoring Program (Weeber and Valliantos 2000, Meyer 2006) and with the standardized protocol prepared by US Fish and Wildlife Service for landbird monitoring (Knutson *et al.* 2008) so that all these large datasets are compatible with each other and can be leveraged.

Chin *et al.* (2015) compared the index of ecological condition (IEC), developed by Howe *et al.* (2007) and Gnass Giese *et al.* (2015), with the index of biotic integrity (IBI) developed and used by the GLCWC (2008; Crewe and Timmermans 2005). The analysis used a similar avian data set acquired by the Marsh Monitoring Program (Tozer 2016). Although the two indices (as well as a third index based on a generalist-specialist designation of bird species) were modestly correlated, significant differences were observed in the ranks of individual wetlands across the range of calculated values. Chin *et al.* (2015) concluded that the use of indicator metrics clearly affects the assessment of wetland quality or condition. The IEC approach was sensitive at both the unimpaired as well as the impaired ends of the disturbance spectrum, whereas the IBI approach was sensitive only at the unimpaired end of the spectrum. Since wetland managers and restoration project teams are interested in both highly disturbed and minimally disturbed conditions, the IEC approach is desirable. However, Chin *et al.* (2015) also pointed out that the IBI method of Crewe and Timmermans (2005) has practical advantages because it encourages wetland monitoring of a selected subset of wetland dependent species. This is especially important for community science programs where field data often are collected by non-scientists.

Our current wetland metrics (Tozer *et al.* 2021, Howe *et al.* 2021) for birds and anurans apply lessons from both the IEC and IBI approaches. The analytical framework for calculating indicator metrics continues to follow the IEC approach, which is flexible and capable of employing multiple (and explicit) disturbance gradients. However, we also have incorporated elements of the IBI approach by limiting the analysis to wetland obligate or wetland facultative species, thus reducing the potential for spurious influences that are not strictly related to wetland quality. More recently, we also have demonstrated that geographic variation in bird and anuran distributions can lead to biogeographic biases that are unrelated to wetland quality. We have attempted to resolve this issue by calculating regional IEC values that use only species that are expected for a given lake or combination of lakes. This effort recognizes 4 distinct regions in the

Great Lakes Basin: Lake Superior, northern Lakes Huron and Michigan, Lake Erie and southern Lakes Huron and Michigan, and Lake Ontario.

Continued assessment of the data will be important for refining our indicator metrics given the large degree of variation due to changing water levels, continental changes in bird populations, and other factors.

BF2. Sampling Methods

Breeding anuran and bird populations are sampled in Great Lakes coastal wetlands using GLCWMP protocols that are regularly vetted for efficiency and effectiveness and which are coordinated as much as possible with the Great Lakes Marsh Monitoring Program delivered by Birds Canada.

Anurans

For anurans, unlimited-distance point counts are used to identify presence and calling intensity of species within each wetland. During a 3-minute sampling period all anuran (frog and toad) vocalizations are recorded on datasheets as occurring within or outside a circular sample area centered on the prescribed sampling point (Weeber and Valliantos 2000, GLCWC 2008). Spatially-explicit records are mapped on a standard data form in order to differentiate the direction of calls from the observer. Field samples for each wetland site consist of 1 – 6 survey points spaced systematically at least 500 m apart in or around the wetland, with the number of points based on wetland size. Point-count samples within each site are located according to the following criteria: 1) points that have been previously sampled within the wetland are selected assuming the locations are consistent with other considerations below, 2) points are located near the most convenient access point(s) to the wetland (in order to encourage long-term monitoring), and 3) to the extent possible, points are placed in different patches of wetland habitat. Sites are visited up to three times per breeding season during peak vocalization periods, with a minimum of 15 days between visits (unless inclement weather or other unforeseen circumstances intervene). Surveys are conducted from one-half hr after sunset to four and one-half hrs after sunset and only during acceptable weather conditions (GLCWC 2008). Dates of sampling are dependent on phenology and general weather conditions. In southern regions, anuran counts can generally be initiated in early April, but are later in the northern regions. Some of the survey sites are sampled by observers with digital audio recorders over an extended point count duration to assess the accuracy of 3-minute point samples.

Calling intensity for each detected species individual or grouping is recorded on the datasheet using a 3-level calling code index:

> Code 1: Calling individuals can be counted and calls are not simultaneous. Exact counts of the number of calling individuals are made in this case.

Code 2: Calls of individuals can be distinguished but some calling is simultaneous. Estimated counts of the number of calling individuals are made in this case.
Code 3: A full calling chorus with calls continuous and overlapping. Reliable counts and even estimates are unrealistic at this level of calling intensity and no counts are required.

At each station, surveyors wait quietly for at least one minute to allow anurans to start calling again after potentially being disturbed by the surveyor's presence. After this initial settle-down period, a timer is set and the surveyors sample for three minutes. Records are made of all species heard calling at an unlimited distance in all directions around the surveyor. Using the appropriate four-letter species code, the relative position of each individual or chorus (codes 1 and 2) is recorded (mapped) on the standard data form. For codes 1 and 2, the number of individuals heard is estimated. Abundance is not recorded for code 3 since there are too many individuals calling to accurately estimate numbers for code 3. Data are entered into the program database after appropriate verification and QA/QC checks.

Birds:
For birds, we use fixed-distance and (simultaneously) unlimited-distance counts at points located at least 250 m apart within each wetland habitat, with the number of points dependent on wetland size. Bird sampling points are the same points used for anurans; however, additional points (i.e., 250 m apart) can be included depending on the configuration and size of the wetland. To get a good representation of the bird community, both shoreline (i.e., approximate upland/wetland interface) and wetland interior stations are sampled. Sample locations are dependent on site accessibility. All species are recorded as within or outside of a 100-m radius circular sample area centered on the sample point. Presence of a pre-designated set of "focal" species (GLCWC 2008) is recorded within 1-min sub-intervals across the 10-min survey. Focal species are those on which GLCWP indicators are based (Tozer et al. 2017). Non-focal species are recorded to the minute interval of first detection only and are not tracked across sub-intervals of time. Known or suspected cases of double-counting individuals beyond 100 m between adjacent points is explicitly noted on the survey form.

Tozer *et al.* (2017) estimated the influence of survey duration on detection probabilities of 14 marsh breeding bird species using data from 23,973 point counts conducted throughout the Great Lakes-St. Lawrence region. The analysis was based on data collected during 2008-2016 by the Great Lakes Marsh Monitoring Program as well as the Great Lakes Coastal Wetland Monitoring Program (CWMP). The authors observed small but significant increases in detection for 7 of 14 species based on 15-min compared to 10-min surveys and concluded that 10-min surveys are superior to 15-min surveys because modest gains in detection of some species does not warrant the additional effort. Further analysis of 3,457 CWMP surveys conducted during 2011-2019 showed that 92% of observations used for calculating wetland bird-based indices of ecological condition (IECs) occur during the first 10 min of point count surveys. IECs were identical based on 10-min or 15-min surveys in 78% of cases, and overall, IECs based on 10-min

surveys differed from those based on 15-min surveys with a mean absolute error of 0.4 (SD = 1.3). Based on these results, we shortened the duration of CWMP bird surveys from 15 min down to 10 min starting in 2020. We are investing saved time by surveying more points wherever possible in sampled wetlands, which will increase the accuracy of IECs at the wetland level and the statistical power of analyses at broader scales, such as at the lake or regional level.

Point count surveys are conducted either from one-half hr before sunrise to 4 hr after sunrise or 4 hr before sunset. The number of birds seen or heard is recorded during 10-minute observation periods (5 min of passive observation followed by 5 min of broadcast calling and passive observation) at each point count station (GLCWC 2008). Wetlands are surveyed twice per breeding season, with a minimum of 15 days between visits, unless unforeseen circumstances prohibit return visits. One count is in the morning and one count is in the evening.

Bird and anuran data are considered highly desirable at wetland sites that are also sampled for invertebrates, fish, and vegetation. Ideally, data are collected for each of these groups in at least 75% of wetlands surveyed. However, wetland sites that bird and anuran crews cannot access are not dropped from the database.

Bird and anuran crews need little in the way of support facilities beyond that provided by the NRRI GIS laboratory that assists them in verifying the accuracy of their GIS equipment, assists with site selection, and provides site maps. Audio playback units are standardized by quality of equipment used and checked with decibel meters to insure proper audio levels. Field survey data sheets include a check that these audio levels are adequate each day. The individuals gathering data on birds and frogs double-enter all data into the CWMP on-line data management system.

BF3. Sample Handling and Custody

Sampling of all bird and anuran populations is completed without handling any biota; it is instead completely based on visual observations or aural detections. Therefore, there is no protocol for handling organisms or a chain of custody for samples. However, data sheets are carefully maintained by field crews, scanned and/or photocopied at the end of each field trip to provide back-up copies, and archived at the regional institution for each field team after the data have been entered into the electronic database. QA/QC recordings made in the field have audio labels at the start and end of each recording and are will be archived in the data management system.

BF4. Analytical Methods Requirements

Performance criteria: All bird and anuran data are recorded on datasheets at the species level. All staff for this group are certified to be able to identify birds and anurans to species. Identification of rare species such as black rail, king rail, or other rare species should include: 1)

when possible, a recording or photo of the species identified, 2) detailed notes of the observation, 3) verification by another individual, presumably one familiar with the species, or 4) with follow-up visits to the site. Rare-species observations are reviewed by the regional team leaders and a determination of acceptance is completed within two months after the end of sampling.

All sampling points are saved using recreational GPS. Recreational GPS accuracy is sufficient for these data. GPS receivers are tested prior to and after the field season by taking repeated readings at known localities visible on aerial photographs. During the field season, field crews are uploading GPS readings at least weekly. At least once per week, GPS points are plotted on aerial photographs of a sampled site and the image is presented to the field crew to verify that points appear to be reasonably accurate. Accuracy during the field season is also checked *a posteriori* by comparing latitude/longitude at easily recognized localities (e.g., road stream crossings) with GPS readings. All tests and results are logged and the logs kept with the appropriate GPS units. In case of GPS or recording/playback equipment failure, the crew will notify their regional laboratory of the need for a replacement unit. Crews note any equipment failures on their field sheets and in the database when they input data.

BF5. Quality Control Requirements

Precision: Precision here refers to how similar duplicates or splits are to themselves and is calculated as a % difference: % difference = (A-B)/((A+B)/2) * 100. Two observers per point listening to and observing the same species ensures precision of the data collected. During field training, pairs of observers compare their independent species identifications made while standing at the same point. Acceptance criteria is 95% agreement in species identified and categories of numbers of individuals. Any discrepancies in species identification are discussed with trainers. The same assessment occurs during mid-season QC checks. In addition, all observers have to pass tests to ensure that they can hear the required frequencies of bird and anuran calls.

Accuracy: The systematic difference from a reference standard or an expert. This will be assessed during the mid-year QC check (see below, this section) and by having recorded calls at the QC sites verified by experts for 2 sites/yr in each regional area. The performance standard is 95% accuracy on identifications and 100% accuracy on knowing when to have identifications checked and record calls (if possible) for expert assistance.

Bias: Systematic bias by a crew or method. Bias will be assessed during the mid-year QC check by observing sample point location at sites and playback call solicitation. The methods used here have known bias against cryptic/secretive species, which will cause systematic differences with other methods which do not have this bias. Detectability analysis has the ability to assess the severity of bias for common vs. secretive species.

Completeness: Calculated as % complete = (# useable sample pts)/(# planned pts) x 100. Sampling completeness is calculated for all sites and depends on whether the target number of visits was achieved for each point for each taxonomic group (birds or anurans, evaluated separately) during appropriate weather conditions, as well as if the visits were within the breeding time window and collected from appropriate habitat. For each taxonomic group, each site must have the majority of its sampling points sampled correctly (meeting the listed criteria) for the data to be included in the database. Because sites have differing numbers of points (1-6) based on site size, the best criteria that apply to all sites is >50% of sampling points meeting these criteria.

Representativeness: How well sites were sampled is determined by plotting all sample points for each site on aerial photographs of the site and by checking the field sheets and database for problem notes and flags, particularly distance between the observation point and the edge of the wetland polygon. How well the sampling dates conform to the breeding window for these taxa is checked. This is done for all sites.

Comparability: Data comparability among crews within the program and to other non-project data is achieved by using standard, accepted methods; creating metadata explaining the methods; and having strict training and QA/QC for all crews and personnel.

Sensitivity: In this case sensitivity refers both to the lowest taxonomic levels achievable, and to the ability to detect uncommon taxa. Identification depends on the ability to see/hear species, which is partially weather and surrounding-condition dependent. Crews note on sample sheets conditions that limited their ability to hear taxa at sites (e.g., windy, road noise, etc.). Crew members also have passed identification tests that also test their ability to hear high frequency calls. In general, all species of birds and anurans can be identified to species. In some cases, it may be difficult to differentiate American coot from common moorhen. In these cases, the generic code (MOOT) will be used to record the detections. Very uncommon taxa may not be detectable because the entire site cannot be sampled; however, at most sites most calling taxa should be detectable by this method. The exceptions are secretive species (see bias).

QA/QC specifics: Because this program encompasses such a large area, unavoidable sources of variation are inherent in any sampling plan; however, our sampling methodology attempts to minimize this variation (e.g., sampling during optimal time-of-day and weather conditions). An objective online testing system is already in place (http://www.birdercertification.org) to insure that target species are included in the visual and audio tests. All field researchers are required to demonstrate proficiency in visual and audio identification of wetland birds and anurans to insure quality control. Field researchers are required to demonstrate their knowledge of the survey protocols prior to field activities (see section A8). The program team includes biologists who have been instrumental in developing bird and anuran monitoring protocols and who have many years of experience in training field workers. Field tools (portable audio players with bird vocalizations, which, when broadcasted into the marsh, elicit calls from secretive species) are

provided to field teams, and audio recordings are made at selected sites to test for accuracy of the field samples. Use of GIS data sources also provides precise locality information. These aspects of the results (species identifications and locality data) are the major targets of data quality control, plus appropriate attention to weather conditions and phenological timing of optimum counting periods.

The PIs coordinate data validation among the different components of the study.
Quality control of point data includes inspection of results in the context of site history, extent of available habitat (as determined from satellite images or other sources), knowledge of the identification skills of contributors, and information about surveys (e.g., survey time, weather conditions, and unusual abundance values). Records with the following attributes require explicit documentation or follow-up field investigation: 1) rare species recorded during only one year and not during subsequent years, 2) rare species observed by a field worker but not known to occur in specific sites by the principal investigators, and 3) rare species recorded in areas where little or no appropriate breeding habitat is present. A list of rare species that require further documentation for the region has been provided to each field team.

Individuals Responsible for Bird/Anuran Sampling:

Western Great Lakes	Bob Howe/Annie Bracey
Central Great Lakes (US side)	Tom Gehring/Bob Howe
Central Great Lakes (CA side)	Doug Tozer
Eastern Great Lakes (US side)	Greg Lawrence/Kathryn Amatangelo
Eastern Great Lakes (CA side)	Doug Tozer

Mid-Year QA/QC Checks:
Anurans and Birds— Bird and anuran PIs evaluate accuracy and correctness of sampling crews at field sites or by analysis of audio recordings collected from the field, with the program QA manager and assistant manager providing oversight on the results of these checks.

Performance criteria include:
- Correct location of sampling points (100%)
- Accuracy of species-level IDs (95%)
- Accuracy of abundance category estimates (90%)
- Correct criteria and techniques for the identification of rare species (100%)
- Correct use of field survey forms (100%)

Failure to meet performance criteria triggers corrective action (see section C1).

BF6. Instrument/Equipment Testing, Inspection, and Maintenance Requirements
The most important field equipment used by researchers in this program is hand-held recreational-grade geo-positioning systems (GPS), various playback recorders (e.g. MP3 players, CD players and speakers), binoculars, spotting scopes, and digital audio recorders (e.g. Sony

PCM-D50 digital recorders). All equipment is tested prior to use to insure the proper functioning of the equipment. For example, multiple tests of GPS waypoints at various locations ensure adequate functioning of the GPS receivers. The database of GPS readings at this standardized point permits quantification of the expected error in locality of data collected during the study. Spare batteries for all units are carried by all crews, along with spare memory chips for the recorders. It is unlikely that any of this equipment can be repaired by field crews in the event of breakage; spare equipment may be available from the nearest regional team laboratory.

BF7. Instrument Calibration and Frequency
Recreational GPS accuracy is sufficient for these data. GPS receivers are tested prior to and after the field season by taking repeated readings at known localities visible on aerial photographs. During the field season, field crews are uploading GPS readings at least weekly. At least once per week, GPS points are plotted on aerial photographs of a sampled site and the image is presented to the field crew to verify that points appear to be reasonably accurate. Accuracy during the field season is also checked *a posteriori* by comparing latitude/longitude at easily recognized localities (e.g., road stream crossings) with GPS readings. All tests and results are logged and the logs kept with the appropriate GPS units.

Broadcast equipment is tested to ensure that they emit species calls at the minimum required volume (80 dB at 1 m in front of the speakers). All of these accuracy checks and tests are logged on field sheets at the time of sampling.

BF8. Inspection/Acceptance Requirements for Supplies and Consumables
N/A

B9. Data Acquisition Requirements (non-direct measurements)

The only non-direct measurement data we use are the data we used to set up the site selection system and land use measures to inform our stressor gradient for use in 3 of our indicator calculations. Wetland polygons were initially based on the Albert and Simonson (2004) Great Lakes coastal wetland GIS coverage. Use of this database for site selection was mandated in the original RFP setting up the Great Lakes Coastal Wetland Monitoring Program (then project) and by the necessity of following the GLCWC sampling protocols. Other data used for site selection include wetland type (Albert *et al.* 2006), the stressor gradient (Danz *et al.* 2005), and GIS background layers (roads, boat launches, land use, etc.) from state and federal agencies. These datasets are used only for logistical and landscape analysis purposes. Most of these data have already been published and peer-reviewed. Non-peer-reviewed information, such as the aerial photos, will be visually checked for correct site location by comparison with the appropriate quad map or Google maps. These photographs are used as supplemental guidance for field crews, rather than to actually generate data. All of the data types mentioned above are in the public domain and are not subject to use restrictions.

Land use data for calculation of the land use and water quality indicator and bird and anuran IEC indicators comes from the North American Land Change Monitoring System (NALCMS) 2010 land cover of North America at 30 meters (from Landsat imagery) (CEC 2015). The NALCMS is a collaborative initiative by agencies across the U.S., Canada, and Mexico to monitor land cover change, and it is produced by the multi-national Commission for Environmental Cooperation (see citation for partner organizations). These land cover data are published and provided as a tool for researchers and meet the QC standards of the associated agencies, including the U.S. Geological Survey. Because the NALCMS includes land cover for both the U.S. and Canada, it standardizes the land cover calculations across all CWMP sites.

Sources for external datasets of all types are tracked. Most external data are from peer-reviewed publications and GIS sources with established metadata lineages – these lineages are maintained. In rare cases in which unpublished data are used, appropriate metadata are generated to describe its origin. Any non-peer-reviewed information, such as the aerial photos, used during the program are visually checked for accuracy and proper identification.

B10. Data Management

In the field, data are recorded on water-proof paper (except bird and anuran crews, who do not work in the rain or the water and can use regular paper), using pencils, water-proof pens, or permanent markers. Site datasheets for all field crews contain the following basic information: site code, date, start and end time, weather and air temperature, regional team code, all names of sampling crew members, and a signature of the person making the entries. Whenever a sample is collected, a detailed description of the location is recorded. This includes GPS coordinates and waypoint number, sampling equipment used, date, and water depth. Any visual observations are logged along with number of containers and sample identification number for all samples collected. Audio recordings have an audio tag with the same information and the existence of these recordings is noted on field data sheets. Any field duplicates receive an entirely separate identification number. Unknown fish and plants are labeled with a collection number, which is included on the sampling form. All completed data sheets are kept in a secure location by field crews and photocopied and/or scanned at the earliest opportunity. Photocopies are archived in a separate location from the original data sheets.

A secure, password-protected online data management system (DMS) has been developed specifically for this program. The system includes data entry forms designed around the layout of field data sheets, which allows field crews to enter data quickly and efficiently, reducing entry errors. Another feature of the data entry system is the use of drop-down menus, which greatly reduces the frequency of data entry errors, particularly for scientific names of taxa. Field crews double-check 100% of the entered data against the field sheets, switching personnel so that a different person checks the data than the person who completed data entry. The DMS

can archive all photo records taken by field crews. The DMS is being expanded and updated to archive bird audio recording files.

The DMS also handles the metadata that accompanies the data (e.g., methods, study design, field data error codes, description of indicator calculations, etc.), which helps ensure the system's usefulness to future researchers, managers, and the public. To accommodate requests for raw data, the DMS can export the data in Microsoft Excel spreadsheet (*.xlsx) and Microsoft Access database (*.mdb) formats. Export files are generated by the DMS each night for all key datasets, and users can also request customized versions of the spreadsheets and databases (e.g., including filters for site and year). Finally, on a semi-annual basis, a comprehensive Access database version of the master database is generated and delivered to EPA and its subcontractor. These exported files give the CWMP dataset an indefinite digital shelf life without any dependency on the infrastructure used for this particular program.

The DMS uses continuous (WAL) archiving on the live database with forced snapshots every three hours between 6 am and 6 pm. The server that houses the DMS has been configured to use CMU's Veeam Backup Solution, and full and incremental snapshots are taken and stored on a local backup server at CMU. Incremental backups are performed nightly and stored at secure locations (on premise and offsite). End-to-end encryption is used for any data that are copied or moved from the backup server to an off-site location. Nightly backup email reports are generated and sent to appropriate CMU IT staff for monitoring purposes. Full system or volume restores can be performed via the previous full snapshot as required. Incremental backups are maintained in the time intervals between full snapshots, which allows for the immediate recovery of folders and individual files in the case of accidental deletion or hardware failure. Additional backup measures for individual components of the DMS are managed by LimnoTech and include: 1) a full nightly SQL backup of the PostgreSQL database and upload to a secure cloud storage service (Sharefile), and 2) storage and source code version control for the CWMP web application in a GitHub repository.

Specifics:
The DMS, including the web application, database, and a geospatial server, are currently hosted on a Windows Server 2019 virtual machine managed by CMU's IT staff. The hardware specifications of the server include an Intel® Xeon® E5-266 v3 @ 2.30 GHz CPU, 8 GB of RAM, and 0.25+ TB of local storage. Internal networking is mixed 100/1000 Mbps and 10 Gbps Ethernet, with two 10 Gbps Internet connections.

The interface to the data is provided through a Microsoft Active Server Pages .NET (ASP.NET) web application that provides typical user and group level authentication and access control. For example, field crews may have access to enter data, but adding new species to drop-down taxa lists requires membership in an 'administrator' group to ensure consistent methodology.

C. ASSESSMENT AND OVERSIGHT

C1. Response/Corrective Actions

Real-Time Remediation of Problems:
A system of immediately reporting any field or laboratory failures, mistakes in sampling protocols, etc., has been instituted. Corrective actions include replacing lost data whenever feasible (e.g., field crews are still on-site or in the vicinity), particularly if the problem would result in a large loss of data for the site or omitting from the database any suspect data that cannot be replaced. Conference calls or webinars with PIs are used in part to discuss and deal with any problems that arise in training, site selection, sampling, sample processing, data entry, or QA/QC. All co-PIs have been advised to contact the management team (Uzarski, Brady, Cooper) immediately if major problems arise that require immediate attention. At least one person on the management team is available at all times when sampling crews are in the field to help deal with questions and problems as they arise. Our experience suggests that an environment of open communication greatly reduces the need for corrective actions later. Cell phone availability by the management team also helps provide a second layer of safety for field crews.

Field crew chiefs are responsible for assessing sampling activities and water quality meter readings, and noting and, when possible, correcting any problems, errors, or values that seem unlikely. Field crew chiefs receive assistance on problem-solving and error-correction via cell phone support from their regional team leader or a management team member.

Failure to meet mid-year QA/QC objectives triggers corrective actions. In most cases, mid-year QA/QC checks are conducted at the laboratory or institution-level even though training and certification (section A8) takes place at the individual level. Table C1.1 lists corrective actions taken when QA/QC performance criteria are not met.

Table C1.1. Quality assurance/quality control performance standards and corrective actions when performance standards are not met during mid-year evaluations.

Protocol	Performance standard	Corrective actions
Site Selection	100% of sites that are rejected by regional teams meet appropriate rejection criteria	Additional training/re-certification of regional team leader (co-PI) and field crew chiefs Sample sites that were erroneously rejected
Water Quality	Appropriate preparation of 100% of sample containers	Additional training/re-certification of regional team leader (co-PI) and field crew chiefs If contamination confirmed/suspected, data will be quarantined from analyses.
	Appropriate maintenance and calibration of water quality meters	Additional training/re-certification of field crew If meter errors confirmed/suspected, data will be quarantined from analyses.
	Appropriate documentation of meter maintenance and calibration	Additional training/re-certification of field crew members Verification of meter performance
	Appropriate labeling and record keeping for data and samples	Additional training/re-certification of field crew Correction of record-keeping and labeling errors when possible. Quarantine of samples that have irreconcilable labeling errors. Flagging of record errors that cannot be corrected.
	Collection equipment rinsing protocol performed properly	Additional training/re-certification of field crew Rinsing protocol re-performed before samples collected. If samples were collected, samples are discarded. Samples re-collected appropriately if crew is still on-site or in the vicinity.
	Samples collected from appropriate locations within a site	Additional training/re-certification of field crew Re-collection of samples if crew is still on-site or in the vicinity.

Table C1.1. (continued).

Protocol	Performance standard	Corrective actions
Macro-phytes	Total percent cover estimates within 10% of expert's estimates	Additional training/re-certification of vegetation crew members
		Correction of coverage estimates on data sheets for affected data.
		Correction of mis-identified plants on datasheets and in database
	100% accuracy completing field data sheets	Correction of field data sheets and training of crew members.
Invertebrates	D-net sweep sampling methods are performed correctly	Additional training/re-certification of relevant field crew members
		Field forms flagged for inappropriately-sampled zones or sites or samples re-collected correctly if crew is still on-site or in the vicinity.
	Habitats are correctly and thoroughly sampled	Additional training/re-certification of relevant field crew members
		Field forms flagged for under- or over-sampled sites or samples re-collected correctly if crew is still on-site or in the vicinity.
	Samples are picked with few invertebrates and mobile taxa missed.	Additional training/re-certification of relevant field crew members
		Field forms flagged for under-picked samples, and those under-represented for mobile taxa or samples re-collected correctly if crew is still on-site or in the vicinity.
	95% of taxa are correctly identified	Additional training of macroinvertebrate laboratory staff
		Re-identification of taxa in question; correction of laboratory forms and database
	100% of samples are properly preserved and labeled	Additional training/re-certification of field crew chiefs and crew members
		Immediate re-preservation of all affected samples. Corrections on labeling wherever possible; removal of data from the database where labeling confusion cannot be fixed.

Table C1.1. (continued).

Protocol	Performance standard	Corrective actions
Fish	Plant morphotypes are correctly identified for setting fyke nets	Additional training/re-certification of field crew chiefs Consult with management team about whether or not error is serious enough to trigger re-sampling of sites Flag datasheets for sites where net setting errors may have occurred but sites will not be re-sampled. Leadership determination of whether data must be excluded from database.
	Fyke nets are set correctly	Additional training/re-certification of field crew chiefs Consult with management team about whether or not error is serious enough to trigger re-sampling of sites Flag datasheets for sites where net setting errors may have occurred but sites will not be re-sampled. . Leadership determination of whether data must be excluded from database.
	95% of species are correctly identified in the field/laboratory	Additional training/re-certification of field crew members Correct errors on field sheets and in database. Exclusion of fish data where IDs cannot be confirmed or corrected.
	100% of fish are handled appropriately	Additional training/re-certification of field crew members
	Unidentifiable and difficult specimens are retained for laboratory ID 100% of the time	Additional training/re-certification of field crew members Flag questionable identifications on data sheets and in database Exclusion of fish data where IDs cannot be confirmed or corrected.

Table C1.1. (continued).

Protocol	Performance standard	Corrective actions
Birds & anurans	95% of sampling locations are located correctly	Additional training/re-certification of field crew members
		Data sheets are flagged so GPS sample locations can be checked
		Data sheets are corrected, if possible, or flagged.
		Data from inappropriate sampling locations is removed from database or quarantined for research use only.
	90% of abundance category estimates agree with those of experts	Additional training/re-certification of field crew members
		Data sheets are corrected, if possible, or flagged. Data are removed from database in severe cases.
	100% of rare species identification attempts are done correctly	Additional training/re-certification of field crew members
		Data sheets are corrected, if possible, or flagged. Data are removed from database in severe cases.
	100% of field survey forms are completed correctly	Additional training/re-certification of field crew members

Any corrective actions affecting data integrity are noted and included in our semi-annual reports to GLNPO.

C2. Reports to Management

Annual program PI meetings cover the following general topics: overall program status, field crew and field work status, lab work status, data entry status, recent problems and solutions, QA/QC reports and analysis, and other topics as needed. These meetings and numerous email communications from the management team keep co-PIs working in close collaboration and solving any problems as they become known.

Regional team leaders, co-PIs, and resident experts conducting mid-season QC checks on field crews write up the results of these QC checks and provide them to their regional team leader, the QA managers, the program leader (Uzarski), and team/crew members who were reviewed. Regional team leaders are responsible for ensuring that these reports are provided on time, and

the QA managers are responsible for notifying regional team leaders in the event that reports are overdue. During these checks, when PIs are out in the field with their teams, crew leaders and members are encouraged to discuss how the sampling season is progressing and trouble-shoot any methods or techniques that are creating difficulty for the crew. This is particularly important during times of very high or very low water levels as crews adjust to these situations.

The semi-annual report to EPA is written by regional team and taxonomic team leaders in collaboration with their co-PIs. The report is compiled and edited by the management team, and is submitted by the program leader (Uzarski). The report includes a program status update, a discussion of QC problems and their solutions and corrective actions, results of QC checks, and a summary of results to date. Reports are distributed to everyone involved with the program and are posted on the program website. Any issue that may have a major impact on program outputs will be reported to the EPA program officer immediately. The program officer is also invited to all annual PI meetings to help ensure close communication with EPA. Numerous additional webinars and conference calls take place on an *ad hoc* basis as PIs and teams communicate and coordinate with each other.

QC audits on field season activities take place at the end of each field season for field data collection activities and are conducted by the PI or field crew chief, if the crew chief has several years of experience with the program. The field season audit covers completeness of sampling activities at each site for all program elements. During the field season, while crews are sampling, crews are directed to check data sheets before they leave a site to ensure all data have been collected and crew leaders audit the data sheets at the end of each day to see if anything was missed while the crew may still be close enough to the site to go back and collect the data. This end-of-season audit is one more check on data completeness and allows PIs to determine how to deal with sites for which some data are missing.

Other elements of the field season audit include sampling gear status and summarization of field crew debriefings (crew leader and crew members). Field crew debriefings at the end of the field season reflect on the season’s sampling, what went well and what did not, where improvements could be made, and where safety could be improved. Field data QC includes data flags on data sheets and how these are being investigated, completeness and location of all samples awaiting processing and checking of expiration dates on samples. PIs inform the QA managers of data and QC issues that cannot be resolved and/or that affect site data integrity (e.g. sites with incomplete data). QA managers ensure that data anomalies are flagged or removed from the data management system.

QC audits on data entry and data management occur in the early spring after most data have been processed over the winter and entered into the database system. Data audits assess completeness of checks for data entry errors; investigations into data 'flags' in the database, how these are being resolved, and identification of data that are too problematic to be trusted; 'mapping' of all GPS points with double-checks on location validity by field crew chiefs; and

audits of how biotic identifications are being verified. QA managers work with the database manager on these audits and resolving issues, with inclusion of co-PIs as necessary. Issues that cannot be fixed or resolved are flagged, quarantined or completely removed from the database, depending on the severity of the issue. EPA is notified of flagged issues when they are provided with the data to ensure they watch for the data flags.

A summarization of the results will be developed by collaboration among all investigators involved with this monitoring program in conjunction with the US EPA program officer. A final report from this work will be written in a similar fashion as the semi-annual reports (see above, this section) and submitted to GLNPO in MS Word format or PDF (or other suitable format) within 90 days of the end of the contract period. This report will include an 1) introduction, 2) description of methods and study area, 3) presentation of results, 4) discussion of the relevance of findings, and 5) a bibliography of pertinent literature. The report will be distributed to everyone who is part of this program and will be made publicly available after review and approval by GLNPO.

D. DATA VALIDATION AND USABILITY

D1. Data Review, Validation, and Verification Requirements

All data entry is subject to a 100% QC check, either by a second person (fish, macroinvertebrate, vegetation, habitat and water chemistry data) or through dual entry with a 100% match validation comparison (bird and anuran data). The review and validation steps below are over and above this 100% QC of data entry of field and lab data.

Quantitative data: After data are entered into the data management system and QC'd for data entry errors (100% QC), the data are checked for out-of-range values. In other words, the data are checked for values that are unlikely to occur and thus may be the result of some sort of error (e.g., very high or low pH or dissolved oxygen values, etc.). Additionally, the highest and lowest values in all datasets are double-checked for data entry errors. Checks consist of reviewing original field data sheets for data entry errors or notes that may provide evidence of a cause for a suspicious value (e.g., 'DO meter would not calibrate correctly'). Checks include confirmation that appropriate instrument calibration and maintenance were being done by field crews. Impossible values that remain (e.g., pH > 14) will be deleted. Unlikely values are flagged and notes included on the data checks that have been done. These data flags allow researchers and others using the data to check these data values during statistical analyses to determine whether or not they are true statistical outliers and to investigate how much they are influencing the results.

Qualitative data: Review of the data is the responsibility of the principal investigators, who devote at least a portion of the post-field season to this effort. Information from existing data

sources as well as experience of the principal investigators is used to identify data records that need to be validated. In many cases, the taxonomic identification errors or transient bird taxa can be detected by evaluating results from multiple surveys at the same site or nearby sites (from this sampling program or from prior datasets) or from knowledge of the natural history of the taxa. Background knowledge about these taxa play an important role in data review, although unexpected but potentially significant observations are not dismissed without follow-up discussion. The lead PIs for each taxonomic group check the taxa lists for uncommon taxa and those that are rarely found in the Great Lakes region. These identifications are verified, if possible, or flagged as suspicious, if verification is not possible.

Indicator calculations: Below we describe how all metrics and indicators are calculated. Metric and indicator calculation is the end goal for all of this data collection. Please note, reference sites are not required when calculating IBI scores. Sites classified as reference and impacted sites were used in the original development of our IBIs (e.g., Cooper et al. 2018, Uzarski et al. 2004). At that time, these sites were selected based on water quality, surrounding land use, and other known anthropogenic disturbances. During original development, the individual IBI metrics were selected and calibrated based on these gradients of human disturbance. Now, IBI scores for fish and macroinvertebrates are calculated without the need to have sites classified as reference or impacted *a priori*. Note also that neither the vegetation IBI nor the anuran or bird IECs are based on the need to have sites classified as reference or impacted.

Water Quality and Land Use:
The Water Quality and Land Use Indicator (hereafter referred to as the Water Quality Indicator for brevity) is calculated using the metrics below (Table D1.1) to compare water quality related disturbance across coastal wetland sites. This index includes ten *in situ* water quality variables, eight land cover variables (as proportions within 1 km and 20 km buffers from the wetlands), and one Principal Component Analysis (PCA). For a water quality and land cover dataset, values within each variable are rank-transformed such that the rank order is proportionate to the inferred degree of anthropogenic disturbance. Variables with high values indicative of low disturbance are ranked positively, with high ranks given to high values. Variables with high values indicative of high disturbance are ranked negatively, such that higher values receive lower ranks. For variables in which extreme (low or high) values indicate disturbance, values are ranked by their distance from the median value. The PCA is calculated from raw values of all water quality variables and land cover proportions and then scaled so that higher PC1 values indicate higher ranked values. Ranks from all 19 variables are then summed and each summed index value is scaled from 0 to 100 (Table D1.2). More details on the calculations can be found in Harrison *et al*. 2019.

Table D1.1. Water Quality and Land Use Indicator variables and the direction of ranking associated with disturbance (positive, negative, or distance from the median).

Indicator Variables	**Rank Direction**	**Variable type**
Water Clarity	Positive	Water Quality
Specific Conductance	Negative	Water Quality
Total Nitrogen	Negative	Water Quality
Nitrite + Nitrate	Median centered	Water Quality
Ammonium	Negative	Water Quality
Total Phosphorus	Negative	Water Quality
Soluble Reactive Phosphorus	Negative	Water Quality
Chlorophyll *a*	Negative	Water Quality
Dissolved Oxygen	Median centered	Water Quality
pH	Median centered	Water Quality
Agriculture – 20 km	Negative	Land Cover
Agriculture – 1 km	Negative	Land Cover
Developed – 20 km	Negative	Land Cover
Developed – 1 km	Negative	Land Cover
Natural Vegetation – 20 km	Positive	Land Cover
Natural Vegetation – 1 km	Positive	Land Cover
Wetlands – 20 km	Positive	Land Cover
Wetlands – 1 km	Positive	Land Cover
PC1	Positive/Negative	PCA

Land use data for calculation of the land use and water quality indicator comes from the North American Land Change Monitoring System (NALCMS) 2010 land cover of North America at 30 meters (from Landsat imagery) (CEC 2015). The NALCMS is a collaborative initiative by agencies across the U.S., Canada, and Mexico to monitor land cover change, and it is produced by the multi-national Commission for Environmental Cooperation (see citation for partner organizations). These land cover data are published and provided as a tool for researchers and meet the QC standards of the associated agencies, including the U.S. Geological Survey. Because the NALCMS includes land cover for both the U.S. and Canada, it standardizes the land cover calculations across all CWMP sites.

Table D1.2. Example of 4 of the 19 variables included in SumRank for six sites in the CWMP dataset, including their raw values, median-centered value (for NO_3^-), ranked values, summed rank (summed total across all 19 variables), and the scaled rank (from 0 to 100).

	Raw values					Variable Ranks				Summed Ranks	
Site	Clarity (cm)	NO_3^- (mg/L)	NO_3^- Center	SpCond. (µS/cm)	Natural Veg 20 km	Clarity Rank	NO_3^- Rank	SpCond Rank	Nat Veg Rank	Summed Rank	Scaled Rank
8	100	0.005	0.019	492	0.259	309	355	69	127	2436	29.1
10	99	1.408	1.384	599	0.231	306	12	41	110	2082	22.6
15	100	0.005	0.019	278	0.300	309	355	240	143	2436	29.1
20	94	0.005	0.019	708	0.292	283	355	21	139	1822	17.9
63	56	0.125	0.101	422	0.347	99	114	94	182	2994	39.2
118	100	0.050	0.026	90	0.582	309	355	21	374	5933	68.4

Interpretation of Water Quality and Land Use Indicator scores

Higher scores are indicative of sites with low disturbance, whereas lower scores are indicative of sites with high disturbance, based on surrounding land cover and *in situ* water chemistry monitoring. Scores for each site are relative to other sites within the dataset used for the calculations; thus the disturbance gradient is dependent on the sites included in the calculations for any given year or among-year comparison.

Vegetation:

1. Compute overall INVASIVE COVER for the **entire site** by summing the coverage values for all invasive plants and dividing by the number of quadrats. This is the INVASIVE COVER score for the entire site (Table D1.3).

2. Compute overall INVASIVE FREQUENCY for the **entire site** by summing the number of quadrats containing invasive species and dividing by the total number of quadrats (Table D1.3).

3. Compute the MEAN CONSERVATISM INDEX for the **entire site** by totaling the conservatism score for each species and dividing by the number of species. This can be rapidly computed using the Michigan FQA software (Herman *et al.* 2001). The mean conservatism index for all species at a site (total) is then divided by the mean conservatism index for native species (native) and this ratio is used in the macrophyte IBI (Table D1.3). Low scores (0.79 or lower) reflect large numbers of exotic species and degraded conditions.

4. Compute overall INVASIVE COVER for the **wet meadow and dry emergent zone** by summing the cover values for all INVASIVE plants in these zones and dividing by the number of quadrats in these zones. This is the INVASIVE COVER score for the wet meadow and dry emergent zone and can be used to estimate the zone quality (Table D1.3).

5. Compute overall INVASIVE FREQUENCY for the **wet meadow and dry emergent zone** by summing the number of quadrats (in these zones) containing INVASIVE species and dividing by the total number of quadrats in the wet meadow and dry emergent zones (Table D1.3).

6. Compute the MEAN CONSERVATISM INDEX for the **wet meadow and dry emergent zone** by totaling the conservatism score for each species in these zones and dividing by the number of species. This can be rapidly computed using the Michigan FQA software (Herman *et al.* 2001). The mean conservatism index for all species (total) in the **wet meadow and dry emergent zone** is divided by the mean conservatism index for native species (native) and this ratio is used in the macrophyte IBI (Table D1.3).

7. Compute overall INVASIVE COVER for the **flooded emergent and submergent zone** by summing the cover values for all invasive plants in these zones and dividing by the number of quadrats in these zones. This is the INVASIVE COVER score for the **flooded emergent and submergent zone** and can be used to estimate the zone quality (Table D1.3).

8. Compute overall INVASIVE FREQUENCY for the **flooded emergent and submergent zone** by dividing the number of quadrats (in these zones) containing invasive species and dividing by the total number of quadrats in the **flooded emergent and submergent zone** (Table D1.3).

9. Compute the MEAN CONSERVATISM INDEX for the **flooded emergent and submergent zone** by totaling the conservatism score for each species in these zones and dividing by the number of species. This can be rapidly computed using the Michigan FQA software (Herman *et al.* 2001). The mean conservatism index for all species (total) in the **flooded emergent and submergent zone** is divided by the conservatism index for native species (native) and the ratio is used in the macrophyte IBI (Table D1.3).

Table D1.3. Macrophyte metrics calculated from quadrat data. Scores will be summed to get an overall IBI score for the site, ranging from 0 to 50.

	Wetland Quality			
Metric	**HIGH (5)**	**MEDIUM (3)**	**LOW (1)**	**VERY LOW (0)**
A: INVASIVE COVER (entire site)[1]	Absent	<25 %	25-50%	>50%
B: INVASIVE FREQ. (entire site)	Absent	<25 %	25-50%	>50%
C: Mean conservatism of entire site (native/total)	>0.95	0.8 -0.95	0.6-0.79	< 0.6
D: INVASIVE COVER (wet meadow and dry emergent zones)[2]	Absent	<25 %	25-50%	>50%
E: INVASIVE FREQ. (wet meadow and dry emergent zones)	Absent	<25 %	25-50%	>50%
F: Mean conservatism score of wet meadow and dry portion of emergent zones (native/total)	>0.95	0.8 -0.95	0.6-0.79	< 0.6
G: INVASIVE COVER (flooded emergent and submergent zone)[3]	Absent	<25 %	25-50%	>50%
H: INVASIVE FREQUENCY (flooded emergent and submergent zone)	Absent	<25 %	25-50%	>50%
I: Mean conservatism of flooded emergent and submergent zones (native/total)	>0.95	0.8 -0.95	0.6-0.79	< 0.6

[1]Invasive species of entire site to include in analysis: *Acorus calamus* (sweet flag), *Agrostis gigantea*, *Butomus umbellatus* (flowering rush), *Centaurea stoebe* (spotted knapweed), *Cirsium arvense* (Canadian thistle), *Cirsium palustre* (marsh thistle), *Cirsium vulgare* (bull thistle), *Glyceria maxima* (tall manna grass), *Hydrocharis morsus-ranae* (European frog's-bit), *Impatiens glandulifera* (touch-me-not), *Iris pseudacorus* (yellow flag), *Lythrum salicaria* (purple loosestrife), *Myriophyllum spicatum* (Eurasian water milfoil), *Nitellopsis obtusa* (starry stonewort), *Phalaris* arundinacea (reed canary grass), *Phragmites australis* (tall reed), *Persicaria lapathifolium* (nodding smartweed), *Potamogeton crispus* (curly pondweed), *Rhamnus cathartica* (common buckthorn), *Rumex crispus* (curly dock), *Solanum dulcamera* (bittersweet nightshade), *Stachys palustris* (hedge-nettle), *Trapa natans* (water chestnut), *Typha angustifolia* (narrow-leaved cattail), *Typha* X *glauca* (hybrid cattail).

[2]Invasive species of wet meadow and dry emergent marsh: *Acorus calamus* (sweet flag), *Agrostis gigantea*, *Centaurea stoebe* (spotted knapweed), *Cirsium arvense*, *Cirsium palustre*, *Cirsium vulgare*, *Glyceria maxima* (tall manna grass), *Impatiens glandulifera, Iris pseudoacorus*, *Lythrum salicaria*, *Phalaris arundinacea*, *Phragmites australis*, *Persicaria lapathifolium*, *Rhamnus cathartica* (common

buckthorn), *Rumex crispus*, *Solanum dulcamera* (bittersweet nightshade), *Stachys palustris* (hedge-nettle), *Typha angustifolia*, *Typha* X *glauca*.

[3]Invasive species of flooded emergent and submergent zone to include in analysis: *Butomus umbellatus*, *Hydrocharis morsus-ranae*, *Lythrum salicaria*, *Myriophyllum spicatum*, *Nitellopsis obtusa* (starry stonewort), *Phalaris arundinacea*, *Phragmites australis*, *Potamogeton crispus*, *Trapa natans* (water chestnut), *Typha angustifolia*, *Typha* X *glauca*.

10. Evaluating wetland quality using submergent and floating plant species:

Evaluating the quality of the portion of a wetland dominated by submergent or floating plants requires a multi-step process (Table D1.4) because several factors can influence the presence and density of these plants. Table D1.4 summarizes the ranks for submergent or emergent zones using submergent and floating plants. It is common for submergent plants to cover only a portion of the bottom substrate in a marsh, so sparse submergent or floating vegetation does not necessarily indicate degraded conditions. High coverage (>75%) of submergent or floating vegetation, with a predominance (>50%) of nutrient-enrichment or sediment-and-increased-turbidity tolerant species (Table D1.5) typically indicates that either agriculture or urban development has resulted in increased nutrient, sediment, or turbidity in the water (Index score = 1), but not to a level that would result in complete elimination of submergent or floating vegetation (Index score = 0). Under such conditions, other submergent and floating plants can be more common, in which case the wetland is considered less degraded (Index score = 3). Submergent and floating vegetation cover ranging from 25-75% is the typical condition for most emergent and submergent wetlands, and Index scores of 3 or 5 indicate this increased quality. Coverage values of less than 25% indicate degraded conditions if only nutrient-enrichment or sediment-and-increased-turbidity tolerant species are present, but are typical for other submergent or floating plant coverage values in many marshes (Index score = 5).

Complete absences of submergent or floating plants can indicate several conditions. In lower stream reaches (drowned river mouths, connecting rivers, or deltas), this absence can indicate that the stream velocity is too high for these plants to persist. Emergent plants may, however, be able to persist in these higher velocity regions of a stream. However, in protected bays or in slow-flowing lower reaches of streams, lack of submergent and floating vegetation typically indicates that sedimentation or turbidity is preventing plant establishment or persistence. When conditions are windy or when turbidity is the result of fine mineral or organic sediments, turbidity is often evident and can be directly linked to lack of wetland vegetation. However, when conditions are calm, surface waters can be clear, but thick, loose sediments will often be evident and easily stirred up during plant sampling. Another complication can be that strong winds may stir up sediment even though conditions are adequate for submergent and floating plants to occupy the wetland. In this case, the wetland should be judged on the basis of the vegetation present, not on the basis of the short-term turbidity.

Table D1.4. Flow chart for determining quality rating of submergent marsh zone or submergent component of an emergent marsh zone.

	Plant Coverage	**Type of submergent plants present**	**Index Score**
Submergent or Floating Vascular Plant Species Present	>75%	>50% nutrient-enrichment tolerant species or sediment-and-increased-turbidity tolerant species[4]	1 LOW
		<50% nutrient-enrichment tolerant species or sediment-and-increased-turbidity tolerant species	3 MODERATE
	25-75%	>50% nutrient-enrichment tolerant species or sediment-and-increased-turbidity tolerant species	3 MODERATE
		<50% nutrient-enrichment tolerant species or sediment-and-increased-turbidity tolerant species	5 HIGH
	<25%	>75% nutrient-enrichment tolerant species or sediment-and-increased-turbidity tolerant species	1 LOW
		<75% nutrient-enrichment tolerant species or sediment-and-increased-turbidity tolerant species	5 HIGH
Submergent or Floating Plant Species Absent	0%	Clear water in rapidly flowing streams or where bottom consists of cobbles or rock	? REQUIRES FURTHER ANALYSIS
		Highly turbid at time of survey, loose bottom sediments	0 VERY LOW
		Clear water, but thick loose bottom sediments	0 VERY LOW
Only Algae Present			0 VERY LOW

[4] Nutrient-enrichment tolerant species or sediment-and-increased-turbidity tolerant species are listed in Table D1.5.

Table D1.5. Species tolerant of nutrient enrichment, sedimentation, or increased turbidity.

Stress	Species
Nutrient Enrichment	*Ceratophyllum demersum*
	Elodea canadensis
	Lemna minor
	Myriophyllum spicatum
	Potamogeton crispus
	Stuckenia pectinata
	Algae, including *Cyanophyta* sp. but not *Chara* sp.
Sedimentation and Increased Turbidity	*Butomus umbellatus*
	Ceratophyllum demersum
	Elodea canadensis
	Heteranthera dubia
	Myriophyllum spicatum
	Potamogeton crispus
	Potamogeton foliosus
	Potamogeton pusillus
	Ranunculus longirostris
	Stuckenia pectinata

Combined standardized score: A combined standardized score is calculated by adding the wetland quality scores from Table D1.3 (A through I) and Table D1.4. Each of these ten numeric scores ranges from zero to five, with a maximum total score of 50 and a minimum score of zero. The Combined numeric quality scores, which can range from 0 to 50, and their equivalent descriptive quality scores are shown in Table D1.6.

Table D1.6. Combined standardized score from Table D1.3 and Table D1.4.

Combined Numeric Score	Combined Descriptive Scores
0-7	Extremely Degraded
8-16	Degraded
17-25	Moderately Degraded
26-33	Moderately Impacted
34-41	Mildly Impacted
42-50	Reference

Macroinvertebrates:

Aquatic macroinvertebrate IBI scores are calculated based on the metrics below. These metrics have been tested extensively for bulrush-dominated fringing wetlands, and will be modified and validated for other plant morphotypes and wetland types as the program accumulates enough data for these analyses.

Table D1.7. Macroinvertebrate IBI for the wet meadow zone: Typically dominated by *Carex* and *Calamagrostis*

Metric	Score=1	Score=3	Score=5
Odonata richness (genera)	0	>0 to 3	>3
Relative abundance Odonata (%)	0 to <1	1 to 5	>5
Crustacea plus Mollusca richness (genera)	<2	2 to 6	>6
Total richness (genera)	<10	10 to 18	>18
Relative abundance Gastropoda (%)	0 to 1	>1 to 25	>25
Relative abundance Sphaeriidae (%)	0	>0 to 3	>3
Evenness	0 to 0.4	>0.4 to 0.7	>0.7
Shannon diversity index	0 to 0.4	>0.4 to 0.9	>0.9
Simpson index	>0.3	>0.15 to 0.3	0 to 0.15

Table D1.8. Macroinvertebrate IBI for the dense *Schoenoplectus* plant morphotype: Dense *Schoenoplectus* mixed with *Pontedaria* and submergents, protected from wave action.

Metric	Score=0	Score=1	Score=3	Score=5	Score=7
Odonata richness (genera)		0	>0 to <1	1 to 2	>2
Relative abundance Odonata (%)		0	>0 to <2	2 to 7	>7
Crustacea + Mollusca richness (genera)		0 to 2	>2 to 4	>4 to 6	>6
Total richness (genera)		<10	10 to 14	>14 to 18	>18
Relative abundance Gastropoda (%)		0	>0 to 2	>2 to 4	>4
Relative abundance Sphaeriidae (%)		0	>0 to 0.05	>0.05	
Ephemeroptera + Trichoptera richness (genera)		0	>0 to 3	>3	
Relative abundance Crustacea + Mollusca (%)		<8	8 to 30	>30	
Relative abundance Isopoda (%)	0	>0 to 1	>1 to 10	>10 to 20	>20
Evenness		0 to 0.4	>0.4 to 0.7	>0.7	

Shannon diversity index	0 to 0.4	>0.4 to 0.9	>0.9
Simpson index	>0.3	>0.15 to 0.3	0 to 0.15

Relative abundance Amphipoda (%):
If 40 to 60 and total score from Dense *Schoenoplectus* morphotype is 41 or greater, subtract 5;
If 40 to 60 and total score from Dense *Schoenoplectus* morphotype is >41, then add 5.

Table D1.9. Macroinvertebrate IBI for the sparse *Schoenoplectus* morphotype: Relatively sparse, usually monodominant stands, subject to direct wave action.

Metric	**Score=0**	**Score=1**	**Score=3**	**Score=5**	**Score=7**
Odonata richness (genera)		0	>0 to <1	1 to 2	>2
Relative abundance Odonata (%)		0	>0 to <1	1 to 2	>2
Crustacea + Mollusca richness (genera)		0 to 2	>2 to 4	>4 to 5	>5
Total richness (genera)		<8	8 to 13	>13 to 17	>17
Relative abundance Gastropoda (%)		0	>0 to 3	>3 to 5	>5
Relative abundance Sphaeriidae (%)		0	>0 to 0.05	>0.05	
Total number of families		0 to 7	>7 to 12	>12	
Rel. abundance Crustacea + Mollusca (%)		<8	8 to 30	>30	
Evenness		0 to 0.4	>0.4 to 0.7	>0.7	
Shannon diversity index		0 to 0.4	>0.4 to 0.9	>0.9	
Simpson index		>0.3	>0.15 to 0.3	0 to 0.15	

<u>Interpretation of macroinvertebrate IBI scores</u>

All values should be based on the median of at least three replicates taken from each plant morphoptype. When all vegetation morphotypes are present, wetlands are scored as follows:

- A total score of 31 to 53 (0% to 15% of possible score) = “Extremely Degraded”, or “in comparison to other Great Lakes wetlands, this wetland is amongst the most impacted”;
- A total score of >53 to 76 (>15% to 30% of possible score) = “Degraded” or “the wetland shows obvious signs of anthropogenic disturbance”;
- A total score of >76 to 106 (>30% to 50% of possible score) = “Moderately Degraded” or “the wetland shows many obvious signs indicative of anthropogenic disturbance;”
- A total score of >106 to 136 (>50% to 70% of possible score) = “Moderately Impacted” or “the wetland shows few, but obvious, signs of anthropogenic disturbance;”

- A total score of >136 to 159 (>70% to 85% of possible score) = “Mildly Impacted” or “the wetland is beginning to show signs indicative of anthropogenic disturbance”;
- A total score of > 159 to 182 (>85% to 100% of possible score) = “Reference Conditions” or “the wetland is among the most pristine.”

When only a subset of vegetation morphotpyes are present, category scores are adjusted as follows:

- Wet Meadow only = 9 to 14; >14 to 19; >19 to 27; >27 to 34; >34 to 39; >39 to 45
- Dense *Schoenoplectus* only = 11 to 19; >19 to 29; >29 to 41; >41 to 53; >53 to 62; >62 to 72
- Sparse *Schoenoplectus* only = 11 to 18; >18 to 26; >26 to 37; >37 to 48; >48 to 56; >56 to 65
- Wet Meadow + Dense *Schoenoplectus* = 20 to 33; >33 to 47; >47 to 66; >66 to 84; >84 to 99; >99 to 113
- Wet Meadow + Sparse *Schoenoplectus* = 20 to 32; >32 to 46; >46 to 64; >64 to 82; >82 to 96; >96 to 110
- Dense and Sparse *Schoenoplectus* = 22 to 38; >38 to 55; >55 to 79; >79 to 102; >102 to 119; >119 to 137

Fish:

Final IBI metrics and scoring thresholds for the four vegetation morphotypes are shown in Table D1.10. Catch per unit effort (CPUE) is catch per net per night; since nets should only be set for a single night for this program, no adjustment is needed to catch per net numbers. Final morphotype scores are calculated by re-scaling the sum of all metrics for a vegetation morphotype to a 100-point scale. Specifics and trait information can be found in Cooper *et al.* 2018.

Table D1.10. Fish IBI calculations for several wetland vegetation morphotypes. See Cooper *et al.* 2018 for full details and trait information.

	Scoring		
Sparse or Dense Bulrush (*Schoenoplectus* spp.)	0	1	2
Evenness	0-0.4	>0.4-0.8	>0.8
Non-native species richness	≥2	1	0
Native Cyprinidae CPUE	0	>0-50	>50
Smallmouth bass CPUE	<2	2-5	>5
% Black+brown bullhead	0	>0-25	>25
Johnny darter CPUE	0	>0-0.34	>0.34
Common carp CPUE	>2	>0-2	0
% Carnivore (invertivore+piscivore+zooplanktivore)	>90	40-90	<40
% Richness of high and extra-high temperature spawners	100	>82-100	0-82
% Richness short-lived species	<20	20-60	>60
% Richness species particularly sensitive to environmental degradation	0	>0-15	>15
Final score for morphotype = (sum of metrics / 22) * 100			
Cattail (*Typha* spp.)			
% Richness native species	<60	60-<100	100
Non-native species richness	>2	1-2	0
% Native Cyprinidae	0-20	>20-50	>50
Rock bass CPUE	0	>0-3	>3
% Black+brown bullhead	0	>0-25	>25
% Richness benthic habitat species	>75	30-75	<30
% Richness nest spawners	0	>0-70	>70
% Richness of high and extra-high temperature spawners	100	60-<100	<60
% Richness large and extra-large species	>40	20-40	<20
% Richness species particularly sensitive to environmental degradation	0	>0-8	>8
Final score for morphotype = (sum of metrics / 20) * 100			

Table D1.10. Continued.

	Scoring		
	0	1	2
Water lily (*Nuphar advena* sp., *Nymphaea odorata* sp.)			
Evenness	<0.5	0.5-0.75	>0.75
Non-native species richness	>2	>0-2	0
Rock bass CPUE	<2	2-6	>6
Smallmouth bass CPUE	0	>0-3	>3
% Black+brown bullhead	<5	5-30	>30
Yellow perch CPUE	0	>0-10	>10
% Common carp	>3	>0-3	0
% Richness carnivore species (invertivore+piscivore+zooplanktivore)	<50	50-75	>75
% Richness vegetation spawners	<15	15-40	>40
% Richness species particularly sensitive to environmental degradation	0	>0-10	>10
Final score for morphotype = (sum of metrics / 20) * 100			
Submersed Aquatic Vegetation			
Evenness	<0.2	0.2-0.80	>0.80
Non-native species richness	>3	1-3	0
% Richness native species	<75	75-95	>95
% Native Cyprinidae	<20	20-60	>60
Johnny darter CPUE	0	>0-2	>2
Rock bass CPUE	0	>0-5	>5
% Common carp	>5	>0-5	0
% Richness carnivore species (invertivore+piscivore+zooplanktivore)	<50	50-80	>80
% Richness large and extra-large species	>40	>8-40	0-8
% Richness short-lived species	<20	20-70	>70
% Richness species particularly sensitive to environmental degradation	<5	5-20	>20
Final score for morphotype = (sum of metrics / 22) * 100			

Birds:

Bird indicators are based on occurrences of targeted wetland species (Table D1.11) during standardized 10 minute point counts (Uzarski *et al*. 2017). The calculations lead to a likelihood-based INDEX OF ECOLOGICAL CONDITION (IEC) based on the methods described by Howe *et al*. (2007a, 2007b), Gnass Giese *et al*. (2015), Jung *et al*. (2020), and Howe *et al*. (2021). In all cases, IEC values range from 0 (most disturbed or lowest possible quality) to 10 (least disturbed or highest quality.

1. Determine PRESENCE OR ABSENCE (1 or 0) of 15 prescribed wetland bird species or species groups (Table D1.11) in either of two standardized 10 minute point counts during the breeding season. A species needs to be present during only one of the two counts to yield a count of 1.

1a. Alternatively, calculate the PROBABILITY of each bird species or species group at multiple points in a wetland, where probability is simply the number of points (each sampled twice) where the species was present divided by the total number of points sampled. This probability method is more robust than the presence or absence method.

2. Obtain parameters for a set of BIOTIC RESPONSE (BR) FUNCTIONS representing each of the targeted wetland species or species groups. These previously derived BR functions are based on a specific environmental gradient. Different sets of functions can be evaluated; results will yield indicator metrics representing the different gradients. Standard BR functions are available showing species' responses to a multivariate gradient representing the "human footprint" impacts on the wetland (Elliott 2018). Variables used to derive the "human footprint" include wetland size, developed land and roads within 2 km of the wetland's center, agricultural land within 2 km, developed/agricultural land in the watershed flowing into the wetland, and human population within the watershed. Note: The BR functions are equivalent to pre-determined COEFFIENTS OF CONSERVATISM often used for plant species. In this case, however, the standards are functional responses rather than single values for each species.

3. Use the field data (PRESENCE OR ABSENCE or PROBABILITY values) and the selected BR FUNCTIONS as input for a computer algorithm in the free, public domain R statistical computing environment (R Core Team 2020). The R code is available with instructions from the Great Lakes Coastal Wetland Monitoring Program (GLCWMP). An Excel spreadsheet for calculating IEC values also is available online. These tools use maximum likelihood estimation to calculate the IEC value, which ranges from 0-10 for a site of interest.

4. IEC values can be calculated for the entire Great Lakes Basin or for one of 4 Great Lakes REGIONS: LO = Lake Ontario; LEsHM = Lake Erie and southern Lakes Huron and Michigan; nLHM = northern Lakes Huron and Michigan; and LS = Lake Superior. Regional calculations use a subset of species (excluding species that are rare or absent in the area) and region-specific BR functions.

Table D1.11. Bird species and species groups used for calculation of Index of Ecological Condition (IEC) metrics.

#	Taxon	Species
1	BITTERN	American Bittern (*Botaurus lentiginosus*) and Least Bittern (*Ixobrychus exilis*)
2	TERNS	Black Tern (*Chlidonias niger*), Common Tern (*Sterna hirundo*), and Forster's Tern (*Sterna forsteri*)
3	COYE	Common Yellowthroat (*Geothlypis trichas*)
4	DABxMAL	Dabbling (marsh) ducks (*Anas* spp., *Mareca* spp., *Aix sponsa*), excluding Mallard (*Anas platyrhynchos*)
5	EAOS	Bald Eagle (*Haliaeetus leucocephalus*) and Osprey (*Pandion haliaetus*)
6	EUST	European Starling (*Sturnus vulgaris*)
7	GBH_GE	Great Blue Heron (*Ardea herodias*) and Great Egret (*Ardea alba*)
8	WREN	Marsh Wren (*Cistothorus palustris*) and Sedge Wren (*Cistothorus stellaris*)
9	MOOT	Common Gallinule (*Gallinula galeata*) and American Coot (*Fulica americana*)
10	PBGR	Pied-billed Grebe (*Podilymbus podiceps*)
11	RWBL	Red-winged Blackbird (*Agelaius phoeniceus*)
12	SACR	Sandhill Crane (*Grus canadensis*)
13	RAIL	Sora (*Porzana carolina*), Virginia Rail (*Rallus limicola*) , King Rail (*Rallus elegans*), and Yellow Rail (*Coturnicops noveboracensis*)
14	SWSP	Swamp Sparrow (*Melospiza georgiana*)
15	RARE	Rare/seldom recorded marsh obligates: Wilson's Snipe (*Gallinago delicata*), Northern Harrier (*Circus hudsonius*), Black-crowned Night Heron (*Nycticorax nycticorax*)

Anurans:

Anuran (frog and toad) indicators are based on occurrences of targeted wetland species (Table D1.12) during standardized samples at a given point during a given year, where a standard sample consist of 3 visits during early spring, late spring, and early summer (Uzarski *et al*. 2017). The timing of these 3 visits depends on thresholds of water and air temperature and therefore the sampling schedules vary among geographic regions and years. Presence/absence (1 or 0) for a species at a given site during a given year is determined by the occurrence (value = 1) or absence (value = 0) during any of the 3 counts. In other words, the value for a given species will be 0 if the species was absent during all 3 seasonal samples.

Values assigned for each species at a given site are used to calculate a likelihood-based INDEX OF ECOLOGICAL CONDITION (IEC) based on the methods described by Howe *et al*. (2007a, 2007b), Gnass Giese *et al*. (2015), Jung *et al*. (2020), and Howe *et al*. (2021). In all cases, IEC

values range from 0 (most disturbed or lowest possible quality) to 10 (least disturbed or highest quality. Details of the method are described below.

1. Determine PRESENCE OR ABSENCE (1 or 0) of 10 prescribed wetland anuran species or species groups (Table D1.12) in any of 3 standardized 3 minute point counts during spring and early summer. A species needs to be present during only one of the 3 counts to yield a count of 1.

1a. Alternatively, calculate the PROBABILITY of each bird species or species group at multiple points in a wetland, where probability is simply the number of points (each sampled 3 times) where the species was present divided by the total number of wetland points sampled. This probability method is more robust than the presence or absence method, but it requires greater sampling effort at each wetland.

2. Obtain parameters for a set of BIOTIC RESPONSE (BR) FUNCTIONS representing each of the targeted wetland species or species groups. These previously derived BR functions are based on a specific environmental gradient. Different sets of functions can be evaluated; results will yield indicator metrics representing the different gradients. Standard BR functions are available showing species' responses to a multivariate gradient representing the "human footprint" impacts on the wetland Elliott (2018). Variables used to derive the "human footprint" include wetland size, developed land and roads within 2 km of the wetland's center, agricultural land within 2 km, developed/agricultural land in the watershed flowing into the wetland, and human population within the watershed. Note: The BR functions are equivalent to pre-determined COEFFIENTS OF CONSERVATISM often used for plant species. In this case, however, the standards are functional responses rather than single values for each species.

3. Use the field data (PRESENCE OR ABSENCE or PROBABILITY values) and the selected BR FUNCTIONS as input for a computer algorithm in the free, public domain R statistical computing environment (R Core Team 2020). The R code is available with instructions from the Great Lakes Coastal Wetland Monitoring Program (GLCWMP). An Excel spreadsheet for calculating IEC values also is available online. These tools use maximum likelihood estimation to calculate the IEC value, which ranges from 0-10 for a site of interest.

4. IEC values can be calculated for the entire Great Lakes Basin or for one of 4 Great Lakes REGIONS: LO = Lake Ontario; LEsHM = Lake Erie and southern Lakes Huron and Michigan; nLHM = northern Lakes Huron and Michigan; and LS = Lake Superior. Regional calculations use a subset of species (excluding species that are rare or absent in the area) and region-specific BR functions.

Table D1.12. Anuran species and species groups used for calculation of Index of Ecological Condition (IEC) metrics.

#	Taxon	Species
1	AMTO	American toad (*Anaxyrus americanus*) or Fowler's toad (*Anaxyrus fowleri*)
2	BULL	American bullfrog (*Lithobates catesbeianus*)
3	GRTR	Eastern gray treefrog (*Dryophytes versicolor*) or Cope's gray treefrog (*Dryophytes chrysoscelis*)
4	CHFR	boreal chorus frog (*Pseudacris maculata*) or western chorus frog (*Pseudacris triseriata*)
5	GRFR	green frog (*Lithobates clamitans*)
6	NLFR	northern leopard frog (*Lithobates pipiens*)
7	SPPE	spring peeper (*Pseudacris crucifer*)
8	WOFO	wood frog (*Lithobates sylvaticus*)
9	OTHE	Other species: pickerel frog (*Lithobates palustris*) or mink frog (*Lithobates septentrionalis*)

D2. Validation and Verification Methods

All field data entered into the data management system are double-checked against the original field data sheets by a second person from the same field crew (100% QC), or have double-entry of data (e.g., bird and anuran data), again 100% QC. We have found that both of these methods are effective at catching data entry errors.

Data that are flagged as suspicious are first checked against field data sheets by the appropriate field crew chiefs; if the data are not typos, then they are brought to the attention of the regional team leader or appropriate co-PI, who applies the appropriate cautionary code flag or removes the data from the database, depending on the data type and error (see D1).

Field data sheets are photocopied or scanned to PDF files as soon as crews return from the field. Copies are archived at each regional lab separately from the original data sheets; scans are archived in a Google folder or on a system that is backed up routinely. Original data sheets are used for data entry and data verification in the data management system. After this is complete, the regional team leader archives the original data sheets.

The data management system is hosted and maintained by CMU with the assistance of a contractor. Each year at the end of the field season the preliminary data is provided to GLNPO. In addition, after QC is complete, that year's data is again be provided to GLNPO to replace the earlier, un-QC'd data. This data delivery occurs in conjunction with the spring semi-annual report to EPA. All flags on data that have not been resolved remain in the DMS and are

provided to GLNPO. The metadata accompanying the data in the DMS explains the various types of flags. In most cases, notes within the DMS explain the cause of flags in more detail. Data users must be pro-active in searching for flags, their cause, and explanation within datasets that they download for use.

D3. Reconciliation with Data Quality Objectives

The primary DQO for this study is accurate and representative measurements of biological indicators for all major Great Lakes coastal wetland complexes, with supporting physical and chemical parameters, all collected in accordance with the Great Lakes Coastal Wetland Monitoring Program. To evaluate how well we have met this DQO, we assess how many of the major coastal wetland complexes we are able to sample, how representative that selection is based on our site selection process, and how well each wetland is sampled (see representativeness under each B5 section). Problems we have previously encountered include fyke nets being washed ashore by storms, fyke net damage by muskrats and turtles, and sampler and meter malfunctions. If these issues cannot be resolved in the field, wetlands that have incomplete sampling for any parameter listed as critical are considered for re-sampling. All such information is included in the data management system.

A secondary DQO is providing the data, site indicators, and general information about the program to managers, management agencies, other researchers, and other interested parties. Michigan EGLE is assisting with the outreach part of the program. QA for this objective consists of ensuring that EGLE staff are included in PI meetings so that they understand the program and are up-to-date, reviewing the lists of contacts, etc, with EGLE to ensure that major stakeholders are not missed, and reviewing all products produced by EGLE to ensure accuracy. Our intention is that only 100% accurate products created using QC’d data be available for use by non-program members.

E. LITERATURE CITED

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Appendix B – USACE 1987 Wetland Delineation Manual

US Army Corps of Engineers
Waterways Experiment Station

Wetlands Research Program Technical Report Y-87-1 (on-line edition)

Corps of Engineers Wetlands Delineation Manual

by Environmental Laboratory



January 1987 - Final Report
Approved For Public Release; Distribution Is Unlimited

The following two letters used as part of the number designating technical reports of research published under the Wetlands Research Program identify the area under which the report was prepared:

	Task		Task
CP	Critical Processes	RE	Restoration & Establishment
DE	Delineation & Evaluation	SM	Stewardship & Management

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PRINTED ON RECYCLED PAPER

Wetlands Research Program

Technical Report Y-87-1
January 1987

Corps of Engineers Wetlands Delineation Manual

by Environmental Laboratory

U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

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Preface to the On-Line Edition

This is an electronic version of the 1987 *Corps of Engineers Wetlands Delineation Manual* (the 1987 Manual). The 1987 Manual is the current Federal delineation manual used in the Clean Water Act Section 404 regulatory program for the identification and delineation of wetlands. Except where noted in the manual, the approach requires positive evidence of hydrophytic vegetation, hydric soils, and wetland hydrology for a determination that an area is a wetland.

The original manual and this on-line edition were prepared by the Environmental Laboratory (EL) of the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. The work was sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE), through the Wetlands Research Program.

The manual was originally published in January 1987, following several years of development and testing of draft versions. Since that time, the use and interpretation of the 1987 Manual have been clarified and updated through a series of guidance documents and memoranda from HQUSACE. This electronic edition does not change the intent or jurisdictional area of the 1987 Manual. It does, however, attempt to clarify the manual and current guidance by including a number of boxed "USER NOTES" indicating where the original manual has been augmented by more recent information or guidance. USER NOTES were written by Dr. James S. Wakeley, EL, WES. Due to re-formatting of the text and insertion of the USER NOTES, page numbers in this edition do not match those in the original edition. Some obsolete material appears in this document as struck-out text (e.g., ~~obsolete material~~), and hypertext links are provided to sources of important supplementary information (e.g., hydric soils lists, wetland plant lists). References cited in the USER NOTES refer to the following guidance documents from HQUSACE:

"Clarification of the Phrase "Normal Circumstances" as it pertains to Cropped Wetlands," Regulatory Guidance Letter (RGL) 90-7 dated 26 September 1990.

"Implementation of the 1987 Corps Wetland Delineation Manual," memorandum from John P. Elmore dated 27 August 1991.

"Questions & Answers on the 1987 Manual," memorandum from John F. Studt dated 7 October 1991.

"Clarification and Interpretation of the 1987 Manual," memorandum from Major General Arthur E. Williams dated 6 March 1992.

"Revisions to National Plant Lists," memorandum from Michael L. Davis dated 17 January 1996.

"NRCS Field Indicators of Hydric Soils," memorandum from John F. Studt dated 21 March 1997.

Copies of the original published manual are available through the National Technical Information Service (phone 703-487-4650, NTIS document number ADA 176734/2INE). The report should be cited as follows:

> Environmental Laboratory. (1987). "Corps of Engineers Wetlands Delineation Manual," Technical Report Y-87-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Useful supplementary information for making wetland determinations can also be found at the following sites on the World Wide Web:

- Hydric soils definition, criteria, and lists
- National list of plant species that occur in wetlands
- Analyses of normal precipitation ranges and growing season limits
- National Wetlands Inventory maps and databases

Preface to the Original Edition

This manual is a product of the Wetlands Research Program (WRP) of the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. The work was sponsored by the Office, Chief of Engineers (OCE), U.S. Army. OCE Technical monitors for the WRP were Drs. John R. Hall and Robert J. Pierce, and Mr. Phillip C. Pierce.

The manual has been reviewed and concurred in by the Office of the Chief of Engineers and the Office of the Assistant Secretary of the Army (Civil Works) ~~as a method approved for voluntary use in the field for a trial period of 1 year~~.

~~This manual is not intended to change appreciably the jurisdiction of the Clean Water Act (CWA) as it is currently implemented. Should any District find that use of this method appreciably contracts or expands jurisdiction in their District as the District currently interprets CWA authority, the District should immediately discontinue use of this method and furnish a full report of the circumstances to the Office of the Chief of Engineers~~.

USER NOTES: Use of the 1987 Manual to identify and delineate wetlands potentially subject to regulation under Section 404 is now mandatory. (HQUSACE, 27 Aug 91)

This manual describes technical guidelines and methods using a multiparameter approach to identify and delineate wetlands for purposes of Section 404 of the Clean Water Act. Appendices of supporting technical information are also provided.

The manual is presented in four parts. Part II was prepared by Dr. Robert T. Huffman, formerly of the Environmental Laboratory (EL), WES, and Dr. Dana R. Sanders, Sr., of the Wetland and Terrestrial Habitat Group (WTHG), Environmental Resources Division (ERD), EL. Dr. Huffman prepared the original version of Part II in 1980, entitled "Multiple Parameter Approach to the Field Identification and Delineation of Wetlands." The original version was distributed to all Corps field elements, as well as other Federal resource and environmental regulatory agencies, for review and comments. Dr. Sanders revised the original version in 1982, incorporating review comments. Parts I, III, and IV

were prepared by Dr. Sanders, Mr. William B. Parker (formerly detailed to WES by the U.S. Department of Agriculture (USDA), Soil Conservation Service (SCS)) and Mr. Stephen W. Forsythe (formerly detailed to WES by the U.S. Department of the Interior, Fish and Wildlife Service (FWS)). Dr. Sanders also served as overall technical editor of the manual. The manual was edited by Ms. Jamie W. Leach of the WES Information Products Division.

The authors acknowledge technical assistance provided by: Mr. Russell F. Theriot, Mr. Ellis J. Clairain, Jr., and Mr. Charles J. Newling, all of WTHG, ERD; Mr. Phillip Jones, former SCS detail to WES; Mr. Porter B. Reed, FWS, National Wetland Inventory, St. Petersburg, Fla.; Dr. Dan K. Evans, Marshall University, Huntington, W. Va.; and the USDA-SCS. The authors also express gratitude to Corps personnel who assisted in developing the regional lists of species that commonly occur in wetlands, including Mr. Richard Macomber, Bureau of Rivers and Harbors; Ms. Kathy Mulder, Kansas City District; Mr. Michael Gilbert, Omaha District; Ms. Vicki Goodnight, Southwestern Division; Dr. Fred Weinmann, Seattle District; and Mr. Michael Lee, Pacific Ocean Division. Special thanks are offered to the CE personnel who reviewed and commented on the draft manual, and to those who participated in a workshop that consolidated the field comments.

The work was monitored at WES under the direct supervision of Dr. Hanley K. Smith, Chief, WTHG, and under the general supervision of Dr. Conrad J. Kirby, Jr., Chief, ERD. Dr. Smith, Dr. Sanders, and Mr. Theriot were Managers of the WRP. Dr. John Harrison was Chief, EL.

Director of WES during the preparation of this report was COL Allen F. Grum, USA. During publication, COL Dwayne G. Lee, CE, was Commander and Director. Technical Director was Dr. Robert W. Whalin.

This report should be cited as follows:

> Environmental Laboratory. (1987). "Corps of Engineers Wetlands Delineation Manual," Technical Report Y-87-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	0.4047	hectares
Fahrenheit degrees	5/9	Celsius degrees[1]
feet	0.3048	metres
inches	2.54	centimetres
miles (U.S. statute)	1.6093	kilometres
square inches	6.4516	square centimetres

[1] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9) (F - 32).

Part I: Introduction

Background

1. Recognizing the potential for continued or accelerated degradation of the Nation's waters, the U.S. Congress enacted the Clean Water Act (hereafter referred to as the Act), formerly known as the Federal Water Pollution Control Act (33 U.S.C. 1344). The objective of the Act is to maintain and restore the chemical, physical, and biological integrity of the waters of the United States. Section 404 of the Act authorizes the Secretary of the Army, acting through the Chief of Engineers, to issue permits for the discharge of dredged or fill material into the waters of the United States, including wetlands.

Purpose and Objectives

Purpose

2. The purpose of this manual is to provide users with guidelines and methods to determine whether an area is a wetland for purposes of Section 404 of the Act.

Objectives

3. Specific objectives of the manual are to:

a. Present technical guidelines for identifying wetlands and distinguishing them from aquatic habitats and other nonwetlands.[1]

b. Provide methods for applying the technical guidelines.

c. Provide supporting information useful in applying the technical guidelines.

[1] Definitions of terms used in this manual are presented in the Glossary, Appendix A.

Scope

4. This manual is limited in scope to wetlands that are a subset of "waters of the United States" and thus subject to Section 404. The term "waters of the United States" has broad meaning and incorporates both deep-water aquatic habitats and special aquatic sites, including wetlands (*Federal Register* 1982), as follows:

a. The territorial seas with respect to the discharge of fill material.

b. Coastal and inland waters, lakes, rivers, and streams that are navigable waters of the United States, including their adjacent wetlands.

c. Tributaries to navigable waters of the United States, including adjacent wetlands.

d. Interstate waters and their tributaries, including adjacent wetlands.

e. All others waters of the United States not identified above, such as isolated wetlands and lakes, intermittent streams, prairie potholes, and other waters that are not a part of a tributary system to interstate waters or navigable waters of the United States, the degradation or destruction of which could affect interstate commerce.

Determination that a water body or wetland is subject to interstate commerce and therefore is a "water of the United States" shall be made independently of procedures described in this manual.

Special aquatic sites

5. The Environmental Protection Agency (EPA) identifies six categories of special aquatic sites in their Section 404 b.(l) guidelines (*Federal Register* 1980), including:

a. Sanctuaries and refuges.

b. Wetlands.

c. Mudflats.

d. Vegetated shallows.

e. Coral reefs.

f. Riffle and pool complexes.

Although all of these special aquatic sites are subject to provisions of the Clean Water Act, this manual considers only wetlands. By definition, wetlands are vegetated. Thus, unvegetated special aquatic sites (e.g., mudflats lacking macrophytic vegetation) are not covered in this manual.

Relationship to wetland classification systems

6. The technical guideline for wetlands does not constitute a classification system. It only provides a basis for determining whether a given area is a wetland for purposes of Section 404, without attempting to classify it by wetland type.

7. Consideration should be given to the relationship between the technical guideline for wetlands and the classification system developed for the Fish and Wildlife Service (FWS), U.S. Department of the Interior, by Cowardin et al. (1979). The FWS classification system was developed as a basis for identifying, classifying, and mapping wetlands, other special aquatic sites, and deepwater aquatic habitats. Using this classification system, the National Wetland Inventory (NWI) is mapping the wetlands, other special aquatic sites, and deepwater aquatic habitats of the United States, and is also developing both a list of plant species that occur in wetlands and an associated plant database. These products should contribute significantly to application of the technical guideline for wetlands. The technical guideline for wetlands as presented in the manual includes most, but not all, wetlands identified in the FWS system. The difference is due to two principal factors:

a. The FWS system includes all categories of special aquatic sites identified in the EPA Section 404 b.(l) guidelines. All other special aquatic sites are clearly within the purview of Section 404; thus, special methods for their delineation are unnecessary.

b. The FWS system requires that a positive indicator of wetlands be present for any one of the three parameters, while the technical guideline for wetlands requires that a positive wetland indicator be present for each parameter (vegetation, soils, and hydrology), except in limited instances identified in the manual.

Organization

8. This manual consists of four parts and four appendices. Part I presents the background, purpose and objectives, scope, organization, and use of the manual.

9. Part II focuses on the technical guideline for wetlands, and stresses the need for considering all three parameters (vegetation, soils, and hydrology) when making wetland determinations. Since wetlands occur in an intermediate posi-

tion along the hydrologic gradient, comparative technical guidelines are also presented for deepwater aquatic sites and nonwetlands.

10. Part III contains general information on hydrophytic vegetation, hydric soils, and wetland hydrology. Positive wetland indicators of each parameter are included.

11. Part IV, which presents methods for applying the technical guideline for wetlands, is arranged in a format that leads to a logical determination of whether a given area is a wetland. Section A contains general information related to application of methods. Section B outlines preliminary data-gathering efforts. Section C discusses two approaches (routine and comprehensive) for making wetland determinations and presents criteria for deciding the correct approach to use. Sections D and E describe detailed procedures for making routine and comprehensive determinations, respectively. The basic procedures are described in a series of steps that lead to a wetland determination.

12. The manual also describes (Part IV, Section F) methods for delineating wetlands in which the vegetation, soils, and/or hydrology have been altered by recent human activities or natural events, as discussed below:

a. The definition of wetlands contains the phrase "under normal circumstances," which was included because there are instances in which the vegetation in a wetland has been inadvertently or purposely removed or altered as a result of recent natural events or human activities. Other examples of human alterations that may affect wetlands are draining, ditching, levees, deposition of fill, irrigation, and impoundments. When such activities occur, an area may fail to meet the diagnostic criteria for a wetland. Likewise, positive hydric soil indicators may be absent in some recently created wetlands. In such cases, an alternative method must be employed in making wetland determinations.

USER NOTES: "Normal circumstances" has been further defined as "the soil and hydrologic conditions that are normally present, without regard to whether the vegetation has been removed." The determination of whether normal circumstances exist in a disturbed area "involves an evaluation of the extent and relative permanence of the physical alteration of wetlands hydrology and hydrophytic vegetation" and consideration of the "purpose and cause of the physical alterations to hydrology and vegetation." (RGL 90-7, 26 Sep 90; HQUSACE, 7 Oct 91)

b. Natural events may also result in sufficient modification of an area that indicators of one or more wetland parameters are absent. For example, changes in river course may significantly alter hydrology, or beaver dams may create new wetland areas that lack hydric soil conditions. Catastrophic events (e.g., fires, avalanches, mudslides,

and volcanic activities) may also alter or destroy wetland indicators on a site.

Such atypical situations occur throughout the United States, and all of these cannot be identified in this manual.

13. Certain wetland types, under the extremes of normal circumstances, may not always meet all the wetland criteria defined in the manual. Examples include prairie potholes during drought years and seasonal wetlands that may lack hydrophytic vegetation during the dry season. Such areas are discussed in Part IV, Section G, and guidance is provided for making wetland determinations in these areas. However, such wetland areas may warrant additional research to refine methods for their delineation.

14. Appendix A is a glossary of technical terms used in the manual. Definitions of some terms were taken from other technical sources, but most terms are defined according to the manner in which they are used in the manual.

15. Data forms for methods presented in Part IV are included in Appendix B. Examples of completed data forms are also provided.

16. Supporting information is presented in Appendices C and D. ~~Appendix C contains lists of plant species that occur in wetlands. Section 1 consists of regional lists developed by a Federal interagency panel. Section 2 consists of shorter lists of plant species that commonly occur in wetlands of each region.~~

USER NOTES: CE-supplied plant lists are obsolete and have been superseded by the May 1988 version of the "National List of Plant Species that Occur in Wetlands" published by the U.S. Fish and Wildlife Service and available on the World Wide Web. (HQUSACE, 27 Aug 91)

Section 3 describes morphological, physiological, and reproductive adaptations associated with hydrophytic species, as well as a list of some species exhibiting such adaptations. Appendix D discusses procedures for examining soils for hydric soil indicators, ~~and also contains a list of hydric soils of the United States~~.

USER NOTES: The hydric soil list published in the 1987 Corps Manual is obsolete. Current hydric soil definition, criteria, and lists are available over the World Wide Web from the U.S.D.A. Natural Resources Conservation Service (NRCS). (HQUSACE, 27 Aug 91, 6 Mar 92)

Use

17. Although this manual was prepared primarily for use by Corps of Engineers (CE) field inspectors, it should be useful to anyone who makes wetland determinations for purposes of Section 404 of the Clean Water Act. The user is

directed through a series of steps that involve gathering of information and decisionmaking, ultimately leading to a wetland determination. A general flow diagram of activities leading to a determination is presented in Figure 1. However, not all activities identified in Figure 1 will be required for each wetland determination. For example, if a decision is made to use a routine determination procedure, comprehensive determination procedures will not be employed.

Premise for use of the manual

18. Three key provisions of the CE/EPA definition of wetlands include:

a. Inundated or saturated soil conditions resulting from permanent or periodic inundation by ground water or surface water.

b. A prevalence of vegetation typically adapted for life in saturated soil conditions (hydrophytic vegetation).

c. The presence of "normal circumstances."

19. Explicit in the definition is the consideration of three environmental parameters: hydrology, soil, and vegetation. Positive wetland indicators of all three parameters are normally present in wetlands. Although vegetation is often the most readily observed parameter, sole reliance on vegetation or either of the other parameters as the determinant of wetlands can sometimes be misleading. Many plant species can grow successfully in both wetlands and nonwetlands, and hydrophytic vegetation and hydric soils may persist for decades following alteration of hydrology that will render an area a nonwetland. The presence of hydric soils and wetland hydrology indicators in addition to vegetation indicators will provide a logical, easily defensible, and technical basis for the presence of wetlands. The combined use of indicators for all three parameters will enhance the technical accuracy, consistency, and credibility of wetland determinations. Therefore, all three parameters were used in developing the technical guideline for wetlands and all approaches for applying the technical guideline embody the multiparameter concept.

Approaches

20. The approach used for wetland delineations will vary, based primarily on the complexity of the area in question. Two basic approaches described in the manual are (a) routine and (b) comprehensive.

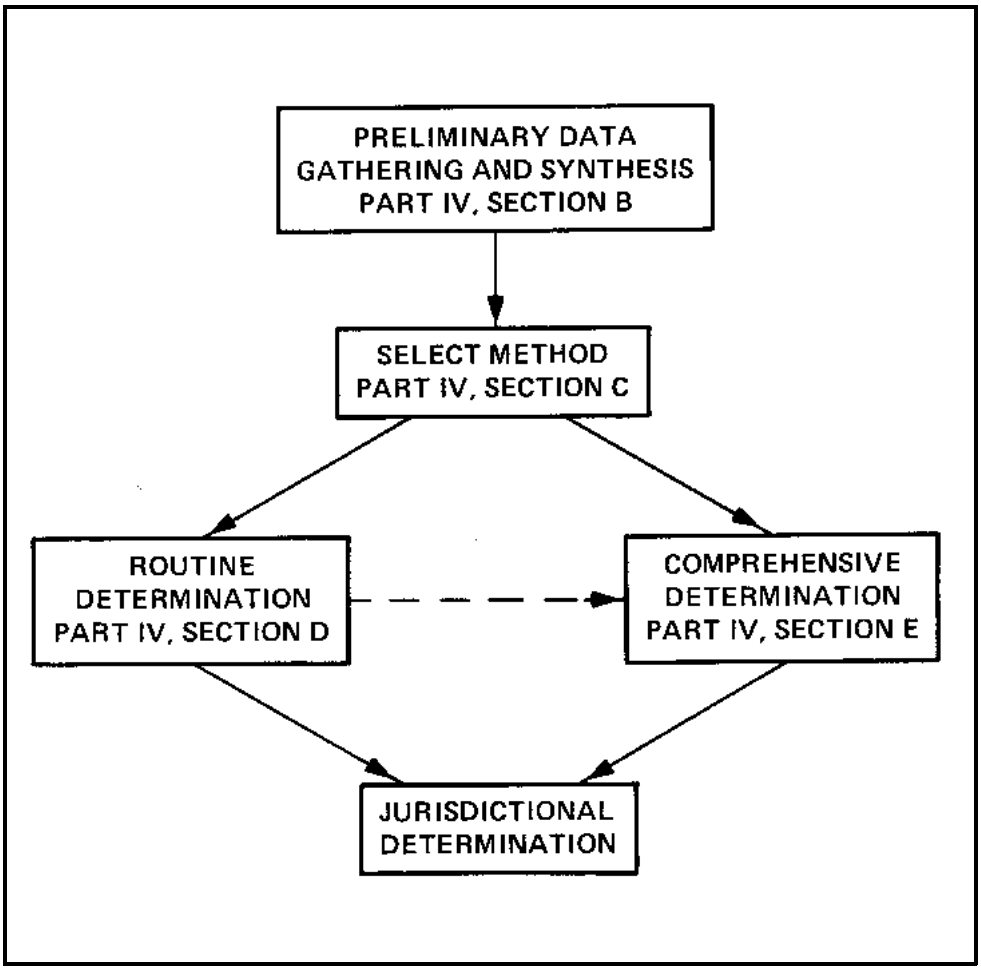


Figure 1. General schematic diagram of activities leading to a wetland/non-wetland determination

21. **Routine approach.** The routine approach normally will be used in the vast majority of determinations. The routine approach requires minimal level of effort, using primarily qualitative procedures. This approach can be further subdivided into three levels of required effort, depending on the complexity of the area and the amount and quality of preliminary data available. The following levels of effort may be used for routine determinations:

a. *Level 1 - Onsite inspection unnecessary.* (Part IV, Section D, Subsection 1).

b. *Level 2 - Onsite inspection necessary.* (Part IV, Section D, Subsection 2).

c. *Level 3 - Combination of Levels 1 and 2.* (Part IV, Section D, Subsection 3).

22. **Comprehensive approach.** The comprehensive approach requires application of quantitative procedures for making wetland determinations. It should

seldom be necessary, and its use should be restricted to situations in which the wetland is very complex and/or is the subject of likely or pending litigation. Application of the comprehensive approach (Part IV, Section E) requires a greater level of expertise than application of the routine approach, and only experienced field personnel with sufficient training should use this approach.

Flexibility

23. Procedures described for both routine and comprehensive wetland determinations have been tested and found to be reliable. However, site-specific conditions may require modification of field procedures. For example, slope configuration in a complex area may necessitate modification of the baseline and transect positions. Since specific characteristics (e.g., plant density) of a given plant community may necessitate the use of alternate methods for determining the dominant species, the user has the flexibility to employ sampling procedures other than those described. However, the basic approach for making wetland determinations should not be altered (i.e., the determination should be based on the dominant plant species, soil characteristics, and hydrologic characteristics of the area in question). The user should document reasons for using a different characterization procedure than described in the manual. *CAUTION: Application of methods described in the manual or the modified sampling procedures requires that the user be familiar with wetlands of the area and use his or her training, experience, and good judgment in making wetland determinations.*

Part II: Technical Guidelines

24. The interaction of hydrology, vegetation, and soil results in the development of characteristics unique to wetlands. Therefore, the following technical guideline for wetlands is based on these three parameters, and diagnostic environmental characteristics used in applying the technical guideline are represented by various indicators of these parameters.

25. Because wetlands may be bordered by both wetter areas (aquatic habitats) and by drier areas (nonwetlands), guidelines are presented for wetlands, deepwater aquatic habitats, and nonwetlands. However, procedures for applying the technical guidelines for deepwater aquatic habitats and nonwetlands are not included in the manual.

Wetlands

26. The following definition, diagnostic environmental characteristics, and technical approach comprise a guideline for the identification and delineation of wetlands:

a. *Definition.* The CE (*Federal Register* 1982) and the EPA (*Federal Register* 1980) jointly define wetlands as: Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

b. *Diagnostic environmental characteristics.* Wetlands have the following general diagnostic environmental characteristics:

(1) *Vegetation.* The prevalent vegetation consists of macrophytes that are typically adapted to areas having hydrologic and soil conditions described in *a* above. Hydrophytic species, due to morphological, physiological, and/or reproductive adaptation(s), have the ability to grow, effectively compete, reproduce, and/or persist in anaerobic

soil conditions.[1] Indicators of vegetation associated with wetlands are listed in paragraph 35.

(2) *Soil*. Soils are present and have been classified as hydric, or they possess characteristics that are associated with reducing soil conditions. Indicators of soils developed under reducing conditions are listed in paragraphs 44 and 45.

(3) *Hydrology*. The area is inundated either permanently or periodically at mean water depths ≤6.6 ft, or the soil is saturated to the surface at some time during the growing season of the prevalent vegetation.[2] Indicators of hydrologic conditions that occur in wetlands are listed in paragraph 49.

c. Technical approach for the identification and delineation of wetlands. Except in certain situations defined in this manual, evidence of a minimum of one positive wetland indicator from each parameter (hydrology, soil, and vegetation) must be found in order to make a positive wetland determination.

Deepwater Aquatic Habitats

27. The following definition, diagnostic environmental characteristics, and technical approach comprise a guideline for deepwater aquatic habitats:

a. Definition. Deepwater aquatic habitats are areas that are permanently inundated at mean annual water depths >6.6 ft or permanently inundated areas ≤6.6 ft in depth that do not support rooted-emergent or woody plant species.[3]

b. Diagnostic environmental characteristics. Deepwater aquatic habitats have the following diagnostic environmental characteristics:

(1) *Vegetation.* No rooted-emergent or woody plant species are present in these permanently inundated areas.

(2) *Soil*. The substrate technically is not defined as a soil if the mean water depth is >6.6 ft or if it will not support rooted emergent or woody plants.

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[1] Species (e.g., *Acer rubrum*) having broad ecological tolerances occur in both wetlands and nonwetlands.

[2] The period of inundation or soil saturation varies according to the hydrologic/soil moisture regime and occurs in both tidal and nontidal situations.

[3] Areas ≤6.6 ft mean annual depth that support only submergent aquatic plants are vegetated shallows, not wetlands.

(3) *Hydrology*. The area is permanently inundated at mean water depths >6.6 ft.

c. Technical approach for the identification and delineation of deepwater aquatic habitats. When any one of the diagnostic characteristics identified in *b* above is present, the area is a deepwater aquatic habitat.

Nonwetlands

28. The following definition, diagnostic environmental characteristics, and technical approach comprise a guideline for the identification and delineation of nonwetlands:

a. Definition. Nonwetlands include uplands and lowland areas that are neither deepwater aquatic habitats, wetlands, nor other special aquatic sites. They are seldom or never inundated, or if frequently inundated, they have saturated soils for only brief periods during the growing season, and, if vegetated, they normally support a prevalence of vegetation typically adapted for life only in aerobic soil conditions.

b. Diagnostic environmental characteristics. Nonwetlands have the following general diagnostic environmental characteristics:

(1) *Vegetation.* The prevalent vegetation consists of plant species that are typically adapted for life only in aerobic soils. These mesophytic and/or xerophytic macrophytes cannot persist in predominantly anaerobic soil conditions.[1]

(2) *Soil*. Soils, when present, are not classified as hydric, and possess characteristics associated with aerobic conditions.

(3) *Hydrology*. Although the soil may be inundated or saturated by surface water or ground water periodically during the growing season of the prevalent vegetation, the average annual duration of inundation or soil saturation does not preclude the occurrence of plant species typically adapted for life in aerobic soil conditions.

c. Technical approach for the identification and delineation of nonwetlands. When any one of the diagnostic characteristics identified in *b* above is present, the area is a nonwetland.

[1] Some species, due to their broad ecological tolerances, occur in both wetlands and nonwetlands (e.g., *Acer rubrum).*

Part III: Characteristics and Indicators of Hydrophytic Vegetation, Hydric Soils, and Wetland Hydrology

Hydrophytic Vegetation

Definition

29. **Hydrophytic vegetation.** Hydrophytic vegetation is defined herein as the sum total of macrophytic plant life that occurs in areas where the frequency and duration of inundation or soil saturation produce permanently or periodically saturated soils of sufficient duration to exert a controlling influence on the plant species present. The vegetation occurring in a wetland may consist of more than one plant community (species association). The plant community concept is followed throughout the manual. Emphasis is placed on the assemblage of plant species that exert a controlling influence on the character of the plant community, rather than on indicator species. Thus, the presence of scattered individuals of an upland plant species in a community dominated by hydrophytic species is not a sufficient basis for concluding that the area is an upland community. Likewise, the presence of a few individuals of a hydrophytic species in a community dominated by upland species is not a sufficient basis for concluding that the area has hydrophytic vegetation. *CAUTION: In determining whether an area is "vegetated" for the purpose of Section 404 jurisdiction, users must consider the density of vegetation at the site being evaluated. While it is not possible to develop a numerical method to determine how many plants or how much biomass is needed to establish an area as being vegetated or unvegetated, it is intended that the predominant condition of the site be used to make that characterization. This concept applies to areas grading from wetland to upland, and from wetland to other waters. This limitation would not necessarily apply to areas which have been disturbed by man or recent natural events.*

30. **Prevalence of vegetation.** The definition of wetlands includes the phrase "prevalence of vegetation." Prevalence, as applied to vegetation, is an imprecise, seldom-used ecological term. As used in the wetlands definition, prevalence refers to the plant community or communities that occur in an area at some point in time. Prevalent vegetation is characterized by the dominant species comprising the plant community or communities. Dominant plant species are those that contribute more to the character of a plant community than other species present, as estimated or measured in terms of some ecological parameter or parameters. The two most commonly used estimates of dominance are basal area (trees) and percent areal cover (herbs). Hydrophytic vegetation is prevalent in an area when the dominant species comprising the plant community or communities are typically adapted for life in saturated soil conditions.

USER NOTES: The "50/20 rule" is the recommended method for selecting dominant species from a plant community when quantitative data are available. The rule states that for each stratum in the plant community, dominant species are the most abundant plant species (when ranked in descending order of abundance and cumulatively totaled) that immediately exceed 50% of the total dominance measure for the stratum, plus any additional species that individually comprise 20% or more of the total dominance measure for the stratum. The list of dominant species is then combined across strata. (HQUSACE, 6 Mar 92)

31. **Typically adapted.** The term "typically adapted" refers to a species being normally or commonly suited to a given set of environmental conditions, due to some morphological, physiological, or reproductive adaptation (Appendix C, Section 3). As used in the CE wetlands definition, the governing environmental conditions for hydrophytic vegetation are saturated soils resulting from periodic inundation or saturation by surface or ground water. These periodic events must occur for sufficient duration to result in anaerobic soil conditions. When the dominant species in a plant community are typically adapted for life in anaerobic soil conditions, hydrophytic vegetation is present. Species ~~listed in Appendix C, Section 1 or 2,~~ that have an indicator status of OBL, FACW, or FAC[1] (Table 1) are considered to be typically adapted for life in anaerobic soil conditions (see paragraph 35*a*).

Influencing factors

32. Many factors (e.g., light, temperature, soil texture and permeability, man-induced disturbance, etc.) influence the character of hydrophytic vegetation. However, hydrologic factors exert an overriding influence on species that can occur in wetlands. Plants lacking morphological, physiological, and/or reproductive adaptations cannot grow, effectively compete, reproduce, and/or persist in areas that are subject to prolonged inundation or saturated soil conditions.

[1] Species having a FAC- indicator status are not considered to be typically adapted for life in anaerobic soil conditions.

Table 1
Plant Indicator Status Categories[1]

Indicator Category	Indicator Symbol	Definition
Obligate Wetland Plants	OBL	Plants that occur almost always (estimated probability >99 percent) in wetlands under natural conditions, but which may also occur rarely (estimated probability <1 percent) in nonwetlands. Examples: *Spartina alterniflora, Taxodium distichum*.
Facultative Wetland Plants	FACW	Plants that occur usually (estimated probability >67 percent to 99 percent) in wetlands, but also occur (estimated probability 1 percent to 33 percent) in nonwetlands. Examples: *Fraxinus pennsylvanica, Cornus stolonifera.*
Facultative Plants	FAC	Plants with a similar likelihood (estimated probability 33 percent to 67 percent) of occurring in both wetlands and nonwetlands. Examples: *Gleditsia triacanthos, Smilax rotundifolia.*
Facultative Upland Plants	FACU	Plants that occur sometimes (estimated probability 1 percent to <33 percent) in wetlands, but occur more often (estimated probability >67 percent to 99 percent) in nonwetlands. Examples: *Quercus rubra, Potentilla arguta.*
Obligate Upland Plants	UPL	Plants that occur rarely (estimated probability <1 percent) in wetlands, but occur almost always (estimated probability >99 percent) in nonwetlands under natural conditions. Examples: *Pinus echinata, Bromus mollis*.

[1] Categories were originally developed and defined by the USFWS National Wetlands Inventory and subsequently modified by the National Plant List Panel. The three facultative categories are subdivided by (+) and (–) modifiers ~~(see Appendix C, Section 1)~~.

Geographic diversity

33. Many hydrophytic vegetation types occur in the United States due to the diversity of interactions among various factors that influence the distribution of hydrophytic species. General climate and flora contribute greatly to regional variations in hydrophytic vegetation. Consequently, the same associations of hydrophytic species occurring in the southeastern United States are not found in the Pacific Northwest. In addition, local environmental conditions (e.g., local climate, hydrologic regimes, soil series, salinity, etc.) may result in broad variations in hydrophytic associations within a given region. For example, a coastal saltwater marsh will consist of different species than an inland freshwater marsh in the same region. An overview of hydrophytic vegetation occurring in each region of the Nation has been published by the CE in a series of eight preliminary wetland guides (Table 2), and a group of wetland and estuarine ecological profiles (Table 3) has been published by FWS.

Classification

34. Numerous efforts have been made to classify hydrophytic vegetation. Most systems are based on general characteristics of the dominant species occurring in each vegetation type. These range from the use of general physiognomic categories (e.g., overstory, subcanopy, ground cover, vines) to specific vegetation types (e.g., forest type numbers as developed by the Society of American Foresters). In other cases, vegetational characteristics are combined with hydrologic features to produce more elaborate systems. The most recent example of such a system was developed for the FWS by Cowardin et al. (1979).

Table 2
List of CE Preliminary Wetland Guides

Region	Publication Date	WES Report No.
Peninsular Florida	February 1978	TR Y-78-2
Puerto Rico	April 1978	TR Y-78-3
West Coast States	April 1978	TR-Y-78-4
Gulf Coastal Plain	May 1978	TR Y-78-5
Interior	May 1982	TR Y-78-6
South Atlantic States	May 1982	TR Y-78-7
North Atlantic States	May 1982	TR Y-78-8
Alaska	February 1984	TR Y-78-9

Table 3
List of Ecological Profiles Produced by the FWS Biological Services Program

Title	Publication Date	FWS Publication No.
"The Ecology of Intertidal Flats of North Carolina"	1979	79/39
"The Ecology of New England Tidal Flats"	1982	81/01
"The Ecology of the Mangroves of South Florida"	1982	81/24
"The Ecology of Bottomland Hardwood Swamps of the Southeast"	1982	81/37
"The Ecology of Southern California Coastal Salt Marshes"	1982	81/54
"The Ecology of New England High Salt Marshes"	1982	81/55
"The Ecology of Southeastern Shrub Bogs (Pocosins) and Carolina Bays"	1982	82/04
"The Ecology of the Apalachicola Bay System"	1984	82/05
"The Ecology of the Pamlico River, North Carolina"	1984	82/06
"The Ecology of the South Florida Coral Reefs"	1984	82/08
"The Ecology of the Sea Grasses of South Florida"	1982	82/25
"The Ecology of Tidal Marshes of the Pacific Northwest Coast"	1983	82/32
"The Ecology of Tidal Freshwater Marshes of the U.S. East Coast"	1984	83/17
"The Ecology of San Francisco Bay Tidal Marshes"	1983	82/23
"The Ecology of Tundra Ponds of the Arctic Coastal Plain"	1984	83/25
"The Ecology of Eelgrass Meadows of the Atlantic Coast"	1984	84/02
"The Ecology of Delta Marshes of Louisiana"	1984	84/09
"The Ecology of Eelgrass Meadows in the Pacific Northwest"	1984	84/24
"The Ecology of Irregularly Flooded Marshes of North-eastern Gulf of Mexico"	(In press)	85(7.1)
"The Ecology of Giant Kelp Forests in California"	1985	85(7.2)

Indicators of hydrophytic vegetation

35. Several indicators may be used to determine whether hydrophytic vegetation is present on a site. However, the presence of a single individual of a hydrophytic species does not mean that hydrophytic vegetation is present. The strongest case for the presence of hydrophytic vegetation can be made when

several indicators, such as those in the following list, are present. However, any one of the following is indicative that hydrophytic vegetation is present:[1]

a. *More than 50 percent of the dominant species are OBL, FACW, or FAC*[2] *(Table 1) on lists of plant species that occur in wetlands.* A national interagency panel has prepared a National List of Plant Species that occur in wetlands. This list categorizes species according to their affinity for occurrence in wetlands. ~~Regional subset lists of the national list, including only species having an indicator status of OBL, FACW, or FAC, are presented in Appendix C, Section 1. The CE has also developed regional lists of plant species that commonly occur in wetlands (Appendix C, Section 2). Either list may be used.~~

USER NOTES: CE-supplied plant lists are obsolete and have been superseded by the May 1988 version of the "National List of Plant Species that Occur in Wetlands" published by the U.S. Fish and Wildlife Service and available on the World Wide Web. Subsequent changes to the May 1988 national plant list, or regional versions of the national list, should not be used until they receive official review and approval. (HQUSACE, 27 Aug 91 and 17 Jan 96)

Note: A District that, on a subregional basis, questions the indicator status of FAC species may use the following option: When FAC species occur as dominants along with other dominants that are not FAC (either wetter or drier than FAC), the FAC species can be considered as neutral, and the vegetation decision can be based on the number of dominant species wetter than FAC as compared to the number of dominant species drier than FAC. When a tie occurs or all dominant species are FAC, the nondominant species must be considered. The area has hydrophytic vegetation when more than 50 percent of all considered species are wetter than FAC. When either all considered species are FAC or the number of species wetter than FAC equals the number of species drier than FAC, the wetland determination will be based on the soil and hydrology parameters. Districts adopting this option should provide documented support to the Corps representative on the regional plant list panel, so that a change in indicator status of FAC species of concern can be pursued. Corps representatives on the regional and national plant list panels will continually strive to ensure that plant species are properly designated on both a regional and subregional basis.

[1] Indicators are listed in order of decreasing reliability. Although all are valid indicators, some are stronger than others. When a decision is based on an indicator appearing in the lower portion of the list, re-evaluate the parameter to ensure that the proper decision was reached.

[2] FAC+ species are considered to be wetter (i.e., have a greater estimated probability of occurring in wetlands) than FAC species, while FAC- species are considered to be drier (i.e., have a lesser estimated probability of occurring in wetlands) than FAC species.

USER NOTES: The FAC-neutral option can not be used to exclude areas as wetlands that meet the basic vegetation rule (i.e., more than 50% of dominant species are FAC, FACW, or OBL) and meet wetland hydrology and hydric soil requirements. Presence of a plant community that satisfies the FAC-neutral option may be used as a secondary indicator of wetland hydrology. (HQUSACE, 6 Mar 92)

b. Other indicators. Although there are several other indicators of hydrophytic vegetation, it will seldom be necessary to use them. However, they may provide additional useful information to strengthen a case for the presence of hydrophytic vegetation. Additional training and/or experience may be required to employ these indicators.

(1) *Visual observation of plant species growing in areas of prolonged inundation and/or soil saturation.* This indicator can only be applied by experienced personnel who have accumulated information through several years of field experience and written documentation (field notes) that certain species commonly occur in areas of prolonged (>10 percent) inundation and/or soil saturation during the growing season. Species such as *Taxodium distichum, Typha latifolia,* and *Spartina alterniflora* normally occur in such areas. Thus, occurrence of species commonly observed in other wetland areas provides a strong indication that hydrophytic vegetation is present. *CAUTION: The presence of standing water or saturated soil on a site is insufficient evidence that the species present are able to tolerate long periods of inundation. The user must relate the observed species to other similar situations and determine whether they are normally found in wet areas, taking into consideration the season and immediately preceding weather conditions.*

(2) *Morphological adaptations.* Some hydrophytic species have easily recognized physical characteristics that indicate their ability to occur in wetlands. A given species may exhibit several of these characteristics, but not all hydrophytic species have evident morphological adaptations. A list of such morphological adaptations and a partial list of plant species with known morphological adaptations for occurrence in wetlands are provided in Appendix C, Section 3.

(3) *Technical literature.* The technical literature may provide a strong indication that plant species comprising the prevalent vegetation are commonly found in areas where soils are periodically saturated for long periods. Sources of available literature include:

(a) *Taxonomic references.* Such references usually contain at least a general description of the habitat in which a species occurs. A habitat description such as, "Occurs in water of streams and lakes and in alluvial floodplains subject to

periodic flooding," supports a conclusion that the species typically occurs in wetlands. Examples of some useful taxonomic references are provided in Table 4.

Table 4
List of Some Useful Taxonomic References

Title	Author(s)
Manual of Vascular Plants of Northeastern United States and Adjacent Canada	Gleason and Cronquist (1963)
Gray's Manual of Botany, 8th edition	Fernald (1950)
Manual of the Southeastern Flora	Small (1933)
Manual of the Vascular Flora of the Carolinas	Radford, Ahles, and Bell (1968)
A Flora of Tropical Florida	Long and Lakela (1976)
Aquatic and Wetland Plants of the Southwestern United States	Correll and Correll (1972)
Arizona Flora	Kearney and Peebles (1960)
Flora of the Pacific Northwest	Hitchcock and Cronquist (1973)
A California Flora	Munz and Keck (1959)
Flora of Missouri	Steyermark (1963)
Manual of the Plants of Colorado	Harrington (1979)
Intermountain Flora - Vascular Plants of the Intermountain West, USA - Vols I and II	Cronquist et al. (1972)
Flora of Idaho	Davis (1952)
Aquatic and Wetland Plants of the Southeastern United States - Vols I and II	Godfrey and Wooten (1979)
Manual of Grasses of the U.S.	Hitchcock (1950)

(b) *Botanical journals.* Some botanical journals contain studies that define species occurrence in various hydrologic regimes. Examples of such journals include: *Ecology, Ecological Monographs, American Journal of Botany, Journal of American Forestry, and Wetlands: The Journal of the Society of Wetland Scientists.*

(c) *Technical reports.* Governmental agencies periodically publish reports (e.g., literature reviews) that contain information on plant species occurrence in relation to hydrologic regimes. Examples of such publications include the CE preliminary regional wetland guides (Table 2) published by the U.S. Army Engineer Waterways Experiment Station (WES) and the wetland community and estuarine profiles of various habitat types (Table 3) published by the FWS.

(d) *Technical workshops, conferences, and symposia.* Publications resulting from periodic scientific meetings contain valuable information that can be used to support a decision regarding the presence of hydrophytic vegetation. These usually address specific regions or wetland types. For example, distribution of bottomland hardwood forest species in relation to hydrologic regimes was examined at a workshop on bottomland hardwood forest wetlands of the Southeastern United States (Clark and Benforado 1981).

(e) *Wetland plant database.* The NWI is producing a Plant Database that contains habitat information on approximately 5,200 plant species that occur at some estimated probability in wetlands, as compiled from the technical literature. When completed, this computerized database will be available to all governmental agencies.

(4) *Physiological adaptations.* Physiological adaptations include any features of the metabolic processes of plants that make them particularly fitted for life in saturated soil conditions. *NOTE: It is impossible to detect the presence of physiological adaptations in plant species during onsite visits.* Physiological adaptations known for hydrophytic species and species known to exhibit these adaptations are listed and discussed in Appendix C, Section 3.

(5) *Reproductive adaptations.* Some plant species have reproductive features that enable them to become established and grow in saturated soil conditions. Reproductive adaptations known for hydrophytic species are presented in Appendix C, Section 3.

Hydric Soils

Definition

36. ~~A hydric soil is a soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation (U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS) 1985, as amended by the National Technical Committee for Hydric Soils (NTCHS) in December 1986).~~

Criteria for hydric soils

37. ~~Based on the above definition, the NTCHS developed the following criteria for hydric soils:~~

a. ~~All Histosols[1] except Folists;~~

b. ~~Soils in Aquic suborders, Aquic subgroups, Albolls suborder, Salorthids great group, or Pell great groups of Vertisols that are:~~

(1) ~~Somewhat poorly drained and have a water table less than 0.5 ft[2] from the surface for a significant period (usually a week or more) during the growing season, or~~

(2) ~~Poorly drained or very poorly drained and have either:~~

(a) ~~A water table at less than 1.0 ft from the surface for a significant period (usually a week or more) during the growing season if permeability is equal to or greater than 6.0 in/hr in all layers within 20 inches; or~~

(b) ~~A water table at less than 1.5 ft from the surface for a significant period (usually a week or more) during the growing season if permeability is less than 6.0 in/hr in any layer within 20 inches; or~~

c. ~~Soils that are ponded for long or very long duration during the growing season; or~~

d. ~~Soils that are frequently flooded for long duration or very long duration during the growing season.~~

USER NOTES: The hydric soil definition and criteria published in the 1987 Corps Manual are obsolete. Current hydric soil definition, criteria, and lists are available over the World Wide Web from the U.S.D.A. Natural Resources Conservation Service (NRCS). (HQUSACE, 27 Aug 91, 6 Mar 92)

A hydric soil may be either drained or undrained, and a drained hydric soil may not continue to support hydrophytic vegetation. Therefore, not all areas having hydric soils will qualify as wetlands. Only when a hydric soil supports hydrophytic vegetation and the area has indicators of wetland hydrology may the soil be referred to as a "wetland" soil.

38. A drained hydric soil is one in which sufficient ground or surface water has been removed by artificial means such that the area will no longer support hydrophyte vegetation. Onsite evidence of drained soils includes:

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[1] Soil nomenclature follows USDA-SCS (1975).

[2] A table of factors for converting Non-SI Units of Measurement to SI (metric) units is presented on page x.

a. Presence of ditches or canals of sufficient depth to lower the water table below the major portion of the root zone of the prevalent vegetation.

b. Presence of dikes, levees, or similar structures that obstruct normal inundation of an area.

c. Presence of a tile system to promote subsurface drainage.

d. Diversion of upland surface runoff from an area.

Although it is important to record such evidence of drainage of an area, a hydric soil that has been drained or partially drained still allows the soil parameter to be met. However, the area will not qualify as a wetland if the degree of drainage has been sufficient to preclude the presence of either hydrophytic vegetation or a hydrologic regime that occurs in wetlands. *NOTE: The mere presence of drainage structures in an area is not sufficient basis for concluding that a hydric soil has been drained; such areas may continue to have wetland hydrology.*

General information

39. Soils consist of unconsolidated, natural material that supports, or is capable of supporting, plant life. The upper limit is air and the lower limit is either bedrock or the limit of biological activity. Some soils have very little organic matter (mineral soils), while others are composed primarily of organic matter (Histosols). The relative proportions of particles (sand, silt, clay, and organic matter) in a soil are influenced by many interacting environmental factors. As normally defined, a soil must support plant life. The concept is expanded to include substrates that could support plant life. For various reasons, plants may be absent from areas that have well-defined soils.

40. A soil profile (Figure 2) consists of various soil layers described from the surface downward. Most soils have two or more identifiable horizons. A soil horizon is a layer oriented approximately parallel to the soil surface, and usually is differentiated from contiguous horizons by characteristics that can be seen or measured in the field (e.g., color, structure, texture, etc.). Most mineral soils have A-, B-, and C-horizons, and many have surficial organic layers (O-horizon). The A-horizon, the surface soil or topsoil, is a zone in which organic matter is usually being added to the mineral soil. It is also the zone from which both mineral and organic matter are being moved slowly downward. The next major horizon is the B-horizon, often referred to as the subsoil. The B-horizon is the zone of maximum accumulation of materials. It is usually characterized by higher clay content and/or more pronounced soil structure development and lower organic matter than the A-horizon. The next major horizon is usually the C-horizon, which consists of unconsolidated parent material that has not been sufficiently weathered to exhibit characteristics of the B-horizon. Clay content and degree of soil structure development in the C-horizon are usually less than in the B-horizon. The lowest major horizon, the R-horizon, consists of consoli-

dated bedrock. In many situations, this horizon occurs at such depths that it has no significant influence on soil characteristics.

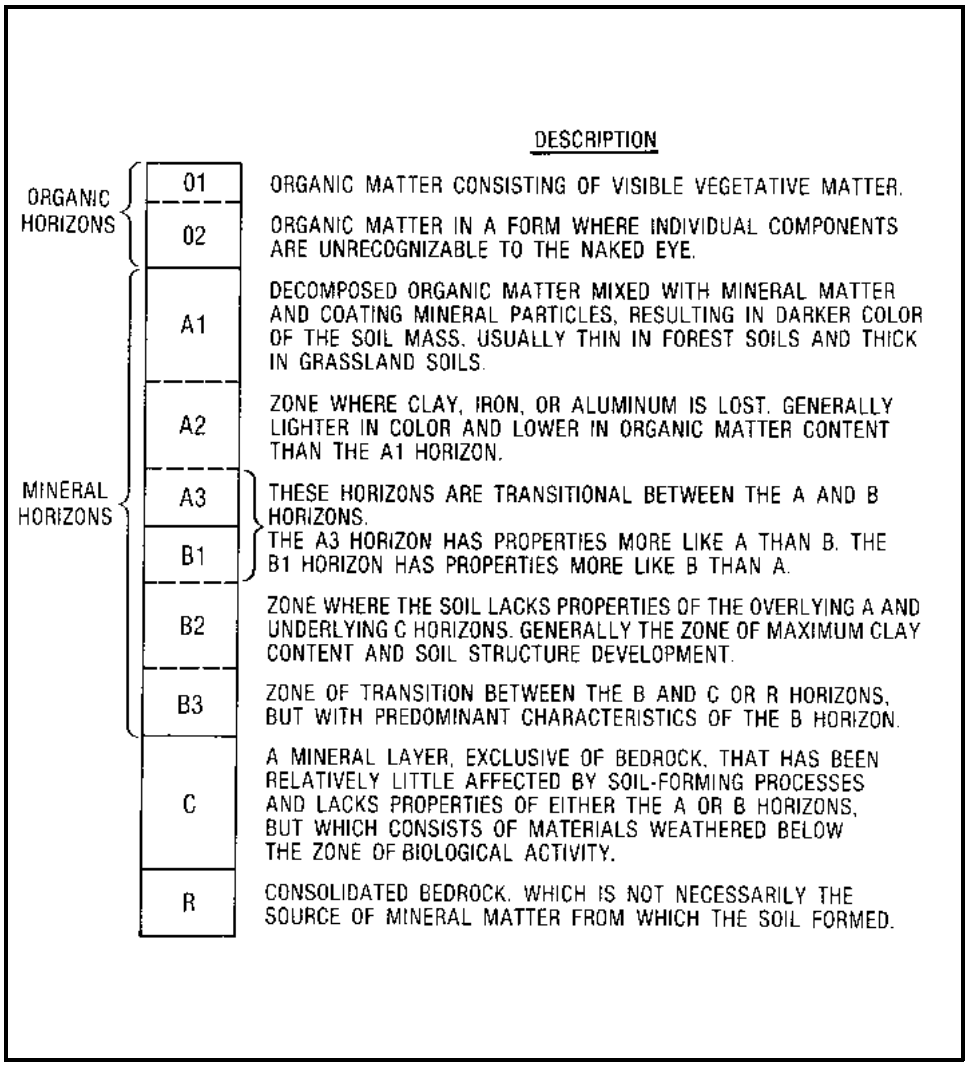


Figure 2. Generalized soil profile

Influencing factors

41. Although all soil-forming factors (climate, parent material, relief, organisms, and time) affect the characteristics of a hydric soil, the overriding influence is the hydrologic regime. The unique characteristics of hydric soils result from the influence of periodic or permanent inundation or soil saturation for sufficient duration to effect anaerobic conditions. Prolonged anaerobic soil conditions lead to a reducing environment, thereby lowering the soil redox potential. This results in chemical reduction of some soil components (e.g., iron and manganese oxides), which leads to development of soil colors and other physical characteristics that usually are indicative of hydric soils.

Classification

42. Hydric soils occur in several categories of the current soil classification system, which is published in *Soil Taxonomy* (USDA-SCS 1975). This classification system is based on physical and chemical properties of soils that can be seen, felt, or measured. Lower taxonomic categories of the system (e.g., soil series and soil phases) remain relatively unchanged from earlier classification systems.

43. Hydric soils may be classified into two broad categories: organic and mineral. Organic soils (Histosols) develop under conditions of nearly continuous saturation and/or inundation. All organic soils are hydric soils except Folists, which are freely drained soils occurring on dry slopes where excess litter accumulates over bedrock. Organic hydric soils are commonly known as peats and mucks. All other hydric soils are mineral soils. Mineral soils have a wide range of textures (sandy to clayey) and colors (red to gray). Mineral hydric soils are those periodically saturated for sufficient duration to produce chemical and physical soil properties associated with a reducing environment. They are usually gray and/or mottled immediately below the surface horizon (see paragraph 44*d*), or they have thick, dark-colored surface layers overlying gray or mottled subsurface horizons.

Wetland indicators (nonsandy soils)

44. Several indicators are available for determining whether a given soil meets the definition and criteria for hydric soils. Any one of the following indicates that hydric soils are present:[1]



Figure 3. Organic soil

a. *Organic soils (Histosols).* A soil is an organic soil when: (1) more than 50 percent (by volume) of the upper 32 inches of soil is composed of organic soil material;[2] or (2) organic soil material of any thickness rests on bedrock. Organic soils (Figure 3) are saturated for long periods and are commonly called peats or mucks.

b. *Histic epipedons.* A histic epipedon is an 8- to 16-inch layer at or near the surface of a mineral hydric soil that is saturated with

[1] Indicators are listed in order of decreasing reliability. Although all are valid indicators, some are stronger indicators than others. When a decision is based on an indicator appearing in the lower portion of the list, re-evaluate the parameter to ensure that the proper decision was reached.

[2] A detailed definition of organic soil material is available in USDA-SCS (1975).

water for 30 consecutive days or more in most years and contains a minimum of 20 percent organic matter when no clay is present or a minimum of 30 percent organic matter when clay content is 60 percent or greater. Soils with histic epipedons are inundated or saturated for sufficient periods to greatly retard aerobic decomposition of the organic surface, and are considered to be hydric soils.

c. *Sulfidic material.* When mineral soils emit an odor of rotten eggs, hydrogen sulfide is present. Such odors are only detected in waterlogged soils that are permanently saturated and have sulfidic material within a few centimeters of the soil surface. Sulfides are produced only in a reducing environment.

d. *Aquic or peraquic moisture regime.* An aquic moisture regime is a reducing one; i.e., it is virtually free of dissolved oxygen because the soil is saturated by ground water or by water of the capillary fringe (USDA-SCS 1975). Because dissolved oxygen is removed from ground water by respiration of microorganisms, roots, and soil fauna, it is also implicit that the soil temperature is above biologic zero (5° C) at some time while the soil is saturated. Soils with *peraquic* moisture regimes are characterized by the presence of ground water always at or near the soil surface. Examples include soils of tidal marshes and soils of closed, landlocked depressions that are fed by permanent streams.

e. *Reducing soil conditions.* Soils saturated for long or very long duration will usually exhibit reducing conditions. Under such conditions, ions of iron are transformed from a ferric valence state to a ferrous valence state. This condition can often be detected in the field by a ferrous iron test. A simple colorimetric field test kit has been developed for this purpose. When a soil extract changes to a pink color upon addition of α,α'-dipyridyl, ferrous iron is present, which indicates a reducing soil environment. *NOTE: This test cannot be used in mineral hydric soils having low iron content, organic soils, and soils that have been desaturated for significant periods of the growing season.*

f. *Soil colors.* The colors of various soil components are often the most diagnostic indicator of hydric soils. Colors of these components are strongly influenced by the frequency and duration of soil saturation, which leads to reducing soil conditions. Mineral hydric soils will be either gleyed or will have bright mottles and/or low matrix chroma. These are discussed below:

(1) *Gleyed soils (gray colors).* Gleyed soils develop when anaerobic soil conditions result in pronounced chemical reduction of iron, manganese, and other elements, thereby producing gray soil colors. Anaerobic conditions that occur in waterlogged soils result in the predominance of reduction processes, and such soils are greatly reduced. Iron is one of the most abundant elements in soils. Under anaerobic conditions, iron in converted from the oxidized (ferric)



Figure 4. Gleyed soil



Figure 5. Soil showing matrix (brown) and mottles (reddish-brown)

state to the reduced (ferrous) state, which results in the bluish, greenish, or grayish colors associated with the gleying effect (Figure 4). Gleying immediately below the A-horizon or 10 inches (whichever is shallower) is an indication of a markedly reduced soil, and gleyed soils are hydric soils. Gleyed soil conditions can be determined by using the gley page of the Munsell Color Book (Munsell Color 1975).

(2) *Soils with bright mottles and/or low matrix chroma.* Mineral hydric soils that are saturated for substantial periods of the growing season (but not long enough to produce gleyed soils) will either have bright mottles and a low matrix chroma or will lack mottles but have a low matrix chroma (see Appendix D, Section 1, for a definition and discussion of "chroma" and other components of soil color). *Mottled* means "marked with spots of contrasting color." Soils that have brightly colored mottles and a low matrix chroma are indicative of a fluctuating water table. The soil *matrix* is the portion (usually more than 50 percent) of a given soil layer that has the predominant color (Figure 5). Mineral hydric soils usually have one of the following color features in the horizon immediately below the A-horizon or 10 inches (whichever is shallower):

(a) Matrix chroma of 2 or less[1] in mottled soils.

(b) Matrix chroma of 1 or less[1] in unmottled soils.

NOTE: The matrix chroma of some dark (black) mineral hydric soils will not conform to the criteria described in (a) and (b) above; in such soils, gray mottles occurring at 10 inches or less are indicative of hydric conditions.

[1] Colors should be determined in soils that have been moistened; otherwise, state that colors are for dry soils.

CAUTION: Soils with significant coloration due to the nature of the parent material (e.g., red soils of the Red River Valley) may not exhibit the above characteristics. In such cases, this indicator cannot be used.

g. Soil appearing on hydric soils list. Using the criteria for hydric soils (paragraph 37), the NTCHS has developed a list of hydric soils.

USER NOTES: The NRCS has developed local lists of hydric soil mapping units that are available from NRCS county and area offices. These local lists are the preferred hydric soil lists to use in making wetland determinations. (HQUSACE, 6 Mar 92)

Listed soils have reducing conditions for a significant portion of the growing season in a major portion of the root zone and are frequently saturated within 12 inches of the soil surface. ~~The NTCHS list of hydric soils is presented in Appendix D, Section 2.~~ *CAUTION: Be sure that the profile description of the mapping unit conforms to that of the sampled soil.*

h. Iron and manganese concretions. During the oxidation-reduction process, iron and manganese in suspension are sometimes segregated as oxides into concretions or soft masses (Figure 6). These accumulations are usually black or dark brown. Concretions >2 mm in diameter occurring within 7.5 cm of the surface are evidence that the soil is saturated for long periods near the surface.



Figure 6. Iron and manganese concretions

Wetland indicators (sandy soils)

45. Not all indicators listed in paragraph 44 can be applied to sandy soils. *In particular, soil color should not be used as an indicator in most sandy soils.* However, three additional soil features may be used as indicators of sandy hydric soils, including:

a. High organic matter content in the surface horizon. Organic matter tends to accumulate above or in the surface horizon of sandy soils that

are inundated or saturated to the surface for a significant portion of the growing season. Prolonged inundation or saturation creates anaerobic conditions that greatly reduce oxidation of organic matter.

b. *Streaking of subsurface horizons by organic matter.* Organic matter is moved downward through sand as the water table fluctuates. This often occurs more rapidly and to a greater degree in some vertical sections of a sandy soil containing high content of organic matter than in others. Thus, the sandy soil appears vertically streaked with darker areas. When soil from a darker area is rubbed between the fingers, the organic matter stains the fingers.

c. *Organic pans.* As organic matter is moved downward through sandy soils, it tends to accumulate at the point representing the most commonly occurring depth to the water table. This organic matter tends to become slightly cemented with aluminum, forming a thin layer of hardened soil (spodic horizon). These horizons often occur at depths of 12 to 30 inches below the mineral surface. Wet spodic soils usually have thick dark surface horizons that are high in organic matter with dull, gray horizons above the spodic horizon.

USER NOTES: The NRCS has developed regional lists of "Field Indicators of Hydric Soils in the United States" (Version 3.2, July 1996, or later). Until approved, these indicators do not supersede those given in the 1987 Corps Manual and supplemental guidance but may be used as supplementary information. Several of the NRCS indicators were developed specifically to help in identifying hydric soils in certain problem soil types (e.g., sandy soils, soils derived from red parent materials, soils with thick, dark surfaces). These indicators may be used under procedures given in the Problem Area section of the 1987 Manual. (HQUSACE, 21 Mar 97)

CAUTION: In recently deposited sandy material (e.g., accreting sandbars), it may be impossible to find any of these indicators. In such cases, consider this as a natural atypical situation.

Wetland Hydrology

Definition

46. The term "wetland hydrology" encompasses all hydrologic characteristics of areas that are periodically inundated or have soils saturated to the surface at some time during the growing season. Areas with evident characteristics of wetland hydrology are those where the presence of water has an overriding influence on characteristics of vegetation and soils due to anaerobic and reducing conditions, respectively. Such characteristics are usually present in areas that

are inundated or have soils that are saturated to the surface for sufficient duration to develop hydric soils and support vegetation typically adapted for life in periodically anaerobic soil conditions. Hydrology is often the least exact of the parameters, and indicators of wetland hydrology are sometimes difficult to find in the field. However, it is essential to establish that a wetland area is periodically inundated or has saturated soils during the growing season.

USER NOTES: The 1987 Manual (see glossary, Appendix A) defines "growing season" as the portion of the year when soil temperature (measured 20 inches below the surface) is above biological zero (5° C or 41° F). This period "can be approximated by the number of frost-free days." Estimated starting and ending dates for the growing season are based on 28° F air temperature thresholds at a frequency of 5 years in 10 (HQUSACE, 6 Mar 92). This information is available in NRCS county soil survey reports or from the NRCS Water and Climate Center in Portland, Oregon, for most weather stations in the country.

Influencing factors

47. Numerous factors (e.g., precipitation, stratigraphy, topography, soil permeability, and plant cover) influence the wetness of an area. Regardless, the characteristic common to all wetlands is the presence of an abundant supply of water. The water source may be runoff from direct precipitation, headwater or backwater flooding, tidal influence, ground water, or some combination of these sources. The frequency and duration of inundation or soil saturation varies from nearly permanently inundated or saturated to irregularly inundated or saturated. Topographic position, stratigraphy, and soil permeability influence both the frequency and duration of inundation and soil saturation. Areas of lower elevation in a floodplain or marsh have more frequent periods of inundation and/or greater duration than most areas at higher elevations. Floodplain configuration may significantly affect duration of inundation. When the floodplain configuration is conducive to rapid runoff, the influence of frequent periods of inundation on vegetation and soils may be reduced. Soil permeability also influences duration of inundation and soil saturation. For example, clayey soils absorb water more slowly than sandy or loamy soils, and therefore have slower permeability and remain saturated much longer. Type and amount of plant cover affect both degree of inundation and duration of saturated soil conditions. Excess water drains more slowly in areas of abundant plant cover, thereby increasing frequency and duration of inundation and/or soil saturation. On the other hand, transpiration rates are higher in areas of abundant plant cover, which may reduce the duration of soil saturation.

Classification

48. Although the interactive effects of all hydrologic factors produce a continuum of wetland hydrologic regimes, efforts have been made to classify wet-

land hydrologic regimes into functional categories. These efforts have focused on the use of frequency, timing, and duration of inundation or soil saturation as a basis for classification. A classification system developed for nontidal areas is presented in Table 5. This classification system was slightly modified from the system developed by the Workshop on Bottomland Hardwood Forest Wetlands of the Southeastern United States (Clark and Benforado 1981). Recent research indicates that duration of inundation and/or soil saturation during the growing season is more influential on the plant community than frequency of inundation/ saturation during the growing season (Theriot, in press). Thus, frequency of inundation and soil saturation are not included in Table 5. ~~The WES has developed a computer program that can be used to transform stream gage data to mean sea level elevations representing the upper limit of each hydrologic zone shown in Table 5. This program is available upon request~~.[1]

USER NOTES: Based on Table 5 and on paragraph 55, Step 8.i., an area has wetland hydrology if it is inundated or saturated to the surface continuously for at least 5% of the growing season in most years (50% probability of recurrence). These areas are wetlands if they also meet hydrophytic vegetation and hydric soil requirements. (HQUSACE, 7 Oct 91 and 6 Mar 92)

Table 5
Hydrologic Zones[1] - Nontidal Areas

Zone	Name	Duration[2]	Comments
I[3]	Permanently inundated	100 percent	Inundation >6.6 ft mean water depth
II	Semipermanently to nearly permanently inundated or saturated	>75 - <100 percent	Inundation defined as ≤6.6 ft mean water depth
III	Regularly inundated or saturated	>25 - 75 percent	
IV	Seasonally inundated or saturated	>12.5 - 25 percent	
V	Irregularly inundated or saturated	≥5 - 12.5 percent	Many areas having these hydrologic characteristics are not wetlands
VI	Intermittently or never inundated or saturated	<5 percent	Areas with these hydrologic characteristics are not wetlands

[1] Zones adapted from Clark and Benforado (1981).
[2] Refers to duration of inundation and/or soil saturation during the growing season.
[3] This defines an aquatic habitat zone.

Wetland indicators

49. Indicators of wetland hydrology may include, but are not necessarily limited to: drainage patterns, drift lines, sediment deposition, watermarks,

[1] ~~R. F. Theriot, Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, P.O. Box 631, Vicksburg, MS 39180.~~

stream gage data and flood predictions, historic records, visual observation of saturated soils, and visual observation of inundation. Any of these indicators may be evidence of wetland hydrologic characteristics. Methods for determining hydrologic indicators can be categorized according to the type of indicator. Recorded data include stream gage data, lake gage data, tidal gage data, flood predictions, and historical records. Use of these data is commonly limited to areas adjacent to streams or other similar areas. Recorded data usually provide both short- and long-term information about frequency and duration of inundation, but contain little or no information about soil saturation, which must be gained from soil surveys or other similar sources. The remaining indicators require field observations. Field indicators are evidence of present or past hydrologic events (e.g., location and height of flooding). Indicators for recorded data and field observations include:[1]

a. *Recorded data.* Stream gage data, lake gage data, tidal gage data, flood predictions, and historical data may be available from the following sources:

(1) *CE District Offices.* Most CE Districts maintain stream, lake, and tidal gage records for major water bodies in their area. In addition, CE planning and design documents often contain valuable hydrologic information. For example, a General Design Memorandum (GDM) usually describes flooding frequencies and durations for a project area. Furthermore, the extent of flooding within a project area is sometimes indicated in the GDM according to elevation (height) of certain flood frequencies (1-, 2-, 5-, 10-year, etc.).

(2) *U.S. Geological Survey (USGS).* Stream and tidal gage data are available from the USGS offices throughout the Nation, and the latter are also available from the National Oceanic and Atmospheric Administration. CE Districts often have such records.

(3) *State, county, and local agencies.* These agencies often have responsibility for flood control/relief and flood insurance.

(4) *Soil Conservation Service Small Watershed Projects.* Planning documents from this agency are often helpful, and can be obtained from the SCS district office in the county.

(5) *Planning documents of developers.*

b. *Field data.* The following field hydrologic indicators can be assessed quickly, and although some of them are not necessarily indicative of hydrologic events that occur only during the growing season, they do provide evidence that inundation and/or soil saturation has occurred:

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[1] Indicators are listed in order of decreasing reliability. Although all are valid indicators, some are stronger indicators than others. When a decision is based on an indicator appearing in the lower portion of the list, re-evaluate the parameter to ensure that the proper decision was reached.

(1) *Visual observation of inundation.* The most obvious and revealing hydrologic indicator may be simply observing the areal extent of inundation. However, because seasonal conditions and recent weather conditions can contribute to surface water being present on a nonwetland site, both should be considered when applying this indicator.

(2) *Visual observation of soil saturation.* Examination of this indicator requires digging a soil pit (Appendix D, Section 1) to a depth of 16 inches and observing the level at which water stands in the hole after sufficient time has been allowed for water to drain into the hole. The required time will vary depending on soil texture. In some cases, the upper level at which water is flowing into the pit can be observed by examining the wall of the hole. This level represents the depth to the water table. The depth to saturated soils will always be nearer the surface due to the capillary fringe.

For soil saturation to impact vegetation, it must occur within a *major portion of the root zone* (usually within 12 inches of the surface) of the prevalent vegetation. The major portion of the root zone is that portion of the soil profile in which more than one half of the plant roots occur. *CAUTION: In some heavy clay soils, water may not rapidly accumulate in the hole even when the soil is saturated. If water is observed at the bottom of the hole but has not filled to the 12-inch depth, examine the sides of the hole and determine the shallowest depth at which water is entering the hole. When applying this indicator, both the season of the year and preceding weather conditions must be considered.*



Figure 7. Watermark on trees

(3) *Watermarks.* Watermarks are most common on woody vegetation. They occur as stains on bark (Figure 7) or other fixed objects (e.g., bridge pillars, buildings, fences, etc.). When several watermarks are present, the highest reflects the maximum extent of recent inundation.

(4) *Drift lines.* This indicator is most likely to be found adjacent to streams or other

sources of water flow in wetlands, but also often occurs in tidal marshes. Evidence consists of deposition of debris in a line on the surface (Figure 8) or debris entangled in aboveground vegetation or other fixed objects. Debris usually consists of remnants of vegetation (branches, stems, and leaves), sediment, litter, and other waterborne materials deposited parallel to the direction of water flow. Drift lines provide an indication of the minimum portion of the area inundated during a flooding event; the maximum level of inundation is generally at a higher elevation than that indicated by a drift line.



Figure 8. Absence of leaf litter

(5) *Sediment deposits.* Plants and other vertical objects often have thin layers, coatings, or depositions of mineral or organic matter on them after inundation (Figure 9). This evidence may remain for a considerable period before it is removed by precipitation or subsequent inundation. Sediment deposition on vegetation and other objects provides an indication of the minimum inundation level. When sediments are primarily organic (e.g., fine organic material, algae), the detritus may become encrusted on or slightly above the soil surface after dewatering occurs (Figure 10).



Figure 9. Sediment deposit on plants



Figure 10. Encrusted detritus

(6) *Drainage patterns within wetlands.* This indicator, which occurs primarily in wetlands

adjacent to streams, consists of surface evidence of drainage flow into or through an area (Figure 11). In some wetlands, this evidence may exist as a drainage pattern eroded into the soil, vegetative matter (debris) piled against thick vegetation or woody stems oriented perpendicular to the direction of water flow, or the absence of leaf litter (Figure 8). Scouring is often evident around roots of persistent vegetation. Debris may be deposited in or along the drainage pattern (Figure 12).



Figure 11. Drainage pattern



Figure 12. Debris deposited in stream channel

CAUTION: Drainage patterns also occur in upland areas after periods of considerable precipitation; therefore, topographic position must also be considered when applying this indicator.

USER NOTES: The hydrology indicators described above are considered to be "primary indicators", any one of which is sufficient evidence that wetland hydrology is present when combined with a hydrophytic plant community and hydric soils. In addition, the following "secondary indicators" may also be used to determine whether wetland hydrology is present. In the absence of a primary indicator, any two secondary indicators must be present to conclude that wetland hydrology is present. Secondary indicators are: presence of oxidized rhizospheres associated with living plant roots in the upper 12 inches of the soil, presence of water-stained leaves, local soil survey hydrology data for identified soils, and the FAC-neutral test of the vegetation. (HQUSACE, 6 Mar 92)

Part IV: Methods

Section A. Introduction

50. Part IV contains sections on preliminary data gathering, method selection, routine determination procedures, comprehensive determination procedures, methods for determinations in atypical situations, and guidance for wetland determinations in natural situations where the three-parameter approach may not always apply.

51. Significant flexibility has been incorporated into Part IV. The user is presented in Section B with various potential sources of information that may be helpful in making a determination, but not all identified sources of information may be applicable to a given situation. *NOTE: The user is not required to obtain information from all identified sources.* Flexibility is also provided in method selection (Section C). Three levels of routine determinations are available, depending on the complexity of the required determination and the quantity and quality of existing information. Application of methods presented in both Section D (routine determinations) and Section E (comprehensive determinations) may be tailored to meet site-specific requirements, especially with respect to sampling design.

52. Methods presented in Sections D and E vary with respect to the required level of technical knowledge and experience of the user. Application of the qualitative methods presented in Section D (routine determinations) requires considerably less technical knowledge and experience than does application of the quantitative methods presented in Section E (comprehensive determinations). The user must at least be able to identify the dominant plant species in the project area when making a routine determination (Section D), and should have some basic knowledge of hydric soils when employing routine methods that require soils examination. Comprehensive determinations require a basic understanding of sampling principles and the ability to identify all commonly occurring plant species in a project area, as well as a good understanding of indicators of hydric soils and wetland hydrology. The comprehensive method should only be employed by experienced field inspectors.

Section B. Preliminary Data Gathering and Synthesis

53. This section discusses potential sources of information that may be helpful in making a wetland determination. When the routine approach is used, it may often be possible to make a wetland determination based on available vegetation, soils, and hydrology data for the area. However, this section deals only with identifying potential information sources, extracting pertinent data, and synthesizing the data for use in making a determination. Based on the quantity and quality of available information and the approach selected for use (Section C), the user is referred to either Section D or Section E for the actual determination. Completion of Section B is not required, but is recommended because the available information may reduce or eliminate the need for field effort and decrease the time and cost of making a determination. However, there are instances in small project areas in which the time required to obtain the information may be prohibitive. In such cases PROCEED to paragraph 55, complete STEPS 1 through 3, and PROCEED to Section D or E.

Data sources

54. Obtain the following information, when available and applicable:

a. USGS quadrangle maps. USGS quadrangle maps are available at different scales. When possible, obtain maps at a scale of 1:24,000; otherwise, use maps at a scale of 1:62,500. Such maps are available from USGS in Reston, VA, and Menlo Park, CA, but they may already be available in the CE District Office. These maps provide several types of information:

(1) Assistance in locating field sites. Towns, minor roads, bridges, streams, and other landmark features (e.g., buildings, cemeteries, water bodies, etc.) not commonly found on road maps are shown on these maps.

(2) Topographic details, including contour lines (usually at 5- or 10-ft contour intervals).

(3) General delineation of wet areas (swamps and marshes). *NOTE: The actual wet area may be greater than that shown on the map because USGS generally maps these areas based on the driest season of the year.*

(4) Latitude, longitude, townships, ranges, and sections. These provide legal descriptions of the area.

(5) Directions, including both true and magnetic north.

(6) Drainage patterns.

(7) General land uses, such as cleared (agriculture or pasture), forested, or urban.

CAUTION: Obtain the most recent USGS maps. Older maps may show features that no longer exist and will not show new features that have developed since the map was constructed. Also, USGS is currently changing the mapping scale from 1:24,000 to 1:25,000.

b. National Wetlands Inventory products.

(1) *Wetland maps.* The standard NWI maps are at a scale of 1:24,000 or, where USGS base maps at this scale are not available, they are at 1:62,500 (1:63,350 in Alaska). Smaller scale maps ranging from 1:100,000 to 1:500,000 are also available for certain areas. Wetlands on NWI maps are classified in accordance with Cowardin et al. (1979). *CAUTION: Since not all delineated areas on NWI maps are wetlands under Department of Army jurisdiction, NWI maps should not be used as the sole basis for determining whether wetland vegetation is present.* NWI "User Notes" are available that correlate the classification system with local wetland community types. An important feature of this classification system is the water regime modifier, which describes the flooding or soil saturation characteristics. Wetlands classified as having a temporarily flooded or intermittently flooded water regime should be viewed with particular caution since this designation is indicative of plant communities that are transitional between wetland and nonwetland. These are among the most difficult plant communities to map accurately from aerial photography. For wetlands "wetter" than temporarily flooded and intermittently flooded, the probability of a designated map unit on recent NWI maps being a wetland (according to Cowardin et al. 1979) at the time of the photography is in excess of 90 percent. *CAUTION: Due to the scale of aerial photography used and other factors, all NWI map boundaries are approximate.* The optimum use of NWI maps is to plan field review (i.e., how wet, big, or diverse is the area?) and to assist during field review, particularly by showing the approximate areal extent of the wetland and its association with other communities. NWI maps are available either as a composite with, or an overlay for, USGS base maps and may be obtained from the NWI Central Office in St. Petersburg, FL, the Wetland Coordinator at each FWS regional office, or the USGS.

USER NOTES: NWI products and information are available over the World Wide Web.

(2) *Plant database*. This database of approximately 5,200 plant species that occur in wetlands provides information (e.g., ranges, habitat, etc.) about each plant species from the technical literature. The database served as a focal point for development of a national list of plants that occur in wetlands (~~Appendix C, Section 1~~).

c. *Soil Surveys.* Soil surveys are prepared by the SCS for political units (county, parish, etc.) in a state. Soil surveys contain several types of information:

(1) General information (e.g., climate, settlement, natural resources, farming, geology, general vegetation types).

(2) Soil maps for general and detailed planning purposes. These maps are usually generated from fairly recent aerial photography. *CAUTION: The smallest mapping unit is 3 acres, and a given soil series as mapped may contain small inclusions of other series.*

(3) Uses and management of soils. Any wetness characteristics of soils will be mentioned here.

(4) Soil properties. Soil and water features are provided that may be very helpful for wetland investigations. Frequency, duration, and timing of inundation (when present) are described for each soil type. Water table characteristics that provide valuable information about soil saturation are also described. Soil permeability coefficients may also be available.

(5) Soil classification. Soil series and phases are usually provided. Published soil surveys will not always be available for the area. If not, contact the county SCS office and determine whether the soils have been mapped.

d. *Stream and tidal gage data.* These documents provide records of tidal and stream flow events. They are available from either the USGS or CE District office.

e. *Environmental impact assessments (EIAs), environmental impact statements (EISs), general design memoranda (GDM), and other similar publications.* These documents may be available from Federal agencies for an area that includes the project area. They may contain some indication of the location and characteristics of wetlands consistent with the required criteria (vegetation, soils, and hydrology), and often contain flood frequency and duration data.

f. *Documents and maps from State, county, or local governments.* Regional maps that characterize certain areas (e.g., potholes, coastal areas, or basins) may be helpful because they indicate the type and character of wetlands.

g. *Remote sensing.* Remote sensing is one of the most useful information sources available for wetland identification and delineation. Recent aerial photography, particularly color infrared, provides a detailed view of an area; thus, recent land use and other features (e.g., general type and areal extent of plant communities and degree of inundation of the area when the photography was taken) can be determined. The multiagency cooperative National High Altitude Aerial Photography Program (HAP) has 1:59,000-scale color infrared photography for approximately 85 percent (December 1985) of the coterminous United States from 1980 to 1985. This photography has excellent resolution and can be ordered enlarged to 1:24,000 scale from USGS. Satellite images provide similar information as aerial photography, although the much smaller scale makes observation of detail more difficult without sophisticated equipment and extensive training. Satellite images provide more recent coverage than aerial photography (usually at 18-day intervals). Individual satellite images are more expensive than aerial photography, but are not as expensive as having an area flown and photographed at low altitudes. However, better resolution imagery is now available with remote sensing equipment mounted on fixed-wing aircraft.

h. *Local individuals and experts.* Individuals having personal knowledge of an area may sometimes provide a reliable and readily available source of information about the area, particularly information on the wetness of the area.

i. *USGS land use and land cover maps.* Maps created by USGS using remotely sensed data and a geographical information system provide a systematic and comprehensive collection and analysis of land use and land cover on a national basis. Maps at a scale of 1:250,000 are available as overlays that show land use and land cover according to nine basic levels. One level is wetlands (as determined by the FWS), which is further subdivided into forested and nonforested areas. Five other sets of maps show political units, hydrologic units, census subdivisions of counties, Federal land ownership, and State land ownership. These maps can be obtained from any USGS mapping center.

j. *Applicant's survey plans and engineering designs.* In many cases, the permit applicant will already have had the area surveyed (often at 1-ft contours or less) and will also have engineering designs for the proposed activity.

Data synthesis

55. When employing Section B procedures, use the above sources of information to complete the following steps:

- *STEP 1 - Identify the project area on a map.* Obtain a USGS quadrangle map (1:24,000) or other appropriate map, and locate the area identified in the permit application. PROCEED TO STEP 2.

- *STEP 2 - Prepare a base map.* Mark the project area boundaries on the map. Either use the selected map as the base map or trace the area on a mylar overlay, including prominent landscape features (e.g., roads, buildings, drainage patterns, etc.). If possible, obtain diazo copies of the resulting base map. PROCEED TO STEP 3.

- *STEP 3 - Determine size of the project area.* Measure the area boundaries and calculate the size of the area. PROCEED TO STEP 4 OR TO SECTION D OR E IF SECTION B IS NOT USED.

- *STEP 4 - Summarize available information on vegetation.* Examine available sources that contain information about the area vegetation. Consider the following:

    a. USGS quadrangle maps. Is the area shown as a marsh or swamp? *CAUTION: Do not use this as the sole basis for determining that hydrophytic vegetation is present.*

    b. NWI overlays or maps. Do the overlays or maps indicate that hydrophytic vegetation occurs in the area? If so, identify the vegetation type(s).

    c. EIAs, EISs, or GDMs that include the project area. Extract any vegetation data that pertain to the area.

    d. Federal, State, or local government documents that contain information about the area vegetation. Extract appropriate data.

    e. Recent (within last 5 years) aerial photography of the area. Can the area plant community type(s) be determined from the photography? Extract appropriate data.

    f. Individuals or experts having knowledge of the area vegetation. Contact them and obtain any appropriate information. *CAUTION: Ensure that the individual providing the information has firsthand knowledge of the area.*

    g. Any published scientific studies of the area plant communities. Extract any appropriate data.

    h. Previous wetland determinations made for the area. Extract any pertinent vegetation data.

    When the above have been considered, PROCEED TO STEP 5.

- *STEP 5 - Determine whether the vegetation in the project area is adequately characterized.* Examine the summarized data (STEP 4) and determine whether the area plant communities are adequately characterized. For routine determinations, the plant community type(s) and the dominant species in each vegetation layer of each community type must be known. Dominant species are those that have the largest relative basal area (overstory),[1] height (woody understory), number of stems (woody vines), or greatest areal cover (herbaceous understory). For comprehensive determinations, each plant community type present in the project area must have been quantitatively described within the past 5 years using accepted sampling and analytical procedures, and boundaries between community types must be known. Record information on DATA FORM 1.[2] In either case, PROCEED TO Section F if there is evidence of recent significant vegetation alteration due to human activities or natural events. Otherwise, PROCEED TO STEP 6.

- *STEP 6 - Summarize available information on area soils.* Examine available information and describe the area soils. Consider the following:

    a. County soil surveys. Determine the soil series present and extract characteristics for each. *CAUTION: Soil mapping units sometimes include more than one soil series.*

    b. Unpublished county soil maps. Contact the local SCS office and determine whether soil maps are available for the area. Determine the soil series of the area, and obtain any available information about possible hydric soil indicators (paragraph 44 or 45) for each soil series.

    c. Published EIAs, EISs, or GDMs that include soils information. Extract any pertinent information.

    d. Federal, State, and/or local government documents that contain descriptions of the area soils. Summarize these data.

    e. Published scientific studies that include area soils data. Summarize these data.

    f. Previous wetland determinations for the area. Extract any pertinent soils data.

    When the above have been considered, PROCEED TO STEP 7.

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[1] This term is used because species having the largest individuals may not be dominant when only a few are present. To use relative basal area, consider both the size and number of individuals of a species and subjectively compare with other species present.

[2] A separate DATA FORM 1 must be used for each plant community type.

- *STEP 7 - Determine whether soils of the project area have been adequately characterized.* Examine the summarized soils data and determine whether the soils have been adequately characterized. For routine determinations, the soil series must be known. For comprehensive determinations, both the soil series and the boundary of each soil series must be known. Record information on DATA FORM 1. In either case, if there is evidence of recent significant soils alteration due to human activities or natural events, PROCEED TO Section F. Otherwise, PROCEED TO STEP 8.

- *STEP 8 - Summarize available hydrology data.* Examine available information and describe the area hydrology. Consider the following:

    a. USGS quadrangle maps. Is there a significant, well-defined drainage through the area? Is the area within a major floodplain or tidal area? What range of elevations occur in the area, especially in relation to the elevation of the nearest perennial watercourse?

    b. NWI overlays or maps. Is the area shown as a wetland or deepwater aquatic habitat? What is the water regime modifier?

    c. EIAs, EISs, or GDMs that describe the project area. Extract any pertinent hydrologic data.

    d. Floodplain management maps. These maps may be used to extrapolate elevations that can be expected to be inundated on a l-, 2-, 3-year, etc., basis. Compare the elevations of these features with the elevation range of the project area to determine the frequency of inundation.

    e. Federal, State, and local government documents (e.g., CE floodplain management maps and profiles) that contain hydrologic data. Summarize these data.

    f. Recent (within past 5 years) aerial photography that shows the area to be inundated. Record the date of the photographic mission.

    g. Newspaper accounts of flooding events that indicate periodic inundation of the area.

    h. SCS County Soil Surveys that indicate the frequency and duration of inundation and soil saturation for area soils. *CAUTION: Data provided only represent average conditions for a particular soil series in its natural undrained state, and cannot be used as a positive hydrologic indicator in areas that have significantly altered hydrology.*

i. Tidal or stream gage data for a nearby water body that apparently influences the area. Obtain the gage data and complete (1) below if the routine approach is used, or (2) below if the comprehensive approach is used (OMIT IF GAGING STATION DATA ARE UNAVAILABLE):

(1) *Routine approach.* Determine the highest water level elevation reached during the growing season for each of the most recent 10 years of gage data. Rank these elevations in descending order and select the fifth highest elevation. Combine this elevation with the mean sea level elevation of the gaging station to produce a mean sea level elevation for the highest water level reached every other year. *NOTE: Stream gage data are often presented as flow rates in cubic feet per second. In these cases, ask the CE District's Hydrology Branch to convert flow rates to corresponding mean sea level elevations and adjust gage data to the site.* Compare the resulting elevations reached biennially with the project area elevations. If the water level elevation exceeds the area elevation, the area is inundated during the growing season on average at least biennially.

(2) *Comprehensive approach.* Complete the following:

(a) *Decide whether hydrologic data reflect the apparent hydrology.* Data available from the gaging station may or may not accurately reflect the area hydrology. Answer the following questions:

- Does the water level of the area appear to fluctuate in a manner that differs from that of the water body on which the gaging station is located? (In ponded situations, the water level of the area is usually higher than the water level at the gaging station.)

- Are less than 10 years of daily readings available for the gaging station?

- Do other water sources that would not be reflected by readings at the gaging station appear to significantly affect the area? For example, do major tributaries enter the stream or tidal area between the area and gaging station?

If the answer to any of the above questions is YES, the area hydrology cannot be determined from the

gaging station data. If the answer to all of the above questions is NO, PROCEED TO (b).

(b) *Analyze hydrologic data.* Subject the hydrologic data to appropriate analytical procedures. Either use duration curves or a computer program developed by WES (available from the Environmental Laboratory upon request) for determining the mean sea level elevation representing the upper limits of wetland hydrology. In the latter case, when the site elevation is lower than the mean sea level elevation representing a 5-percent duration of inundation and saturation during the growing season, the area has a hydrologic regime that may occur in wetlands. *NOTE: Duration curves do not reflect the period of soil saturation following dewatering.*

When all of the above have been considered, PROCEED TO STEP 9.

- *STEP 9 - Determine whether hydrology is adequately characterized.* Examine the summarized data and determine whether the hydrology of the project area is adequately characterized. For routine determinations, there must be documented evidence of frequent inundation or soil saturation during the growing season. For comprehensive determinations, there must be documented quantitative evidence of frequent inundation or soil saturation during the growing season, based on at least 10 years of stream or tidal gage data. Record information on DATA FORM 1. In either case, if there is evidence of recent significant hydrologic alteration due to human activities or natural events, PROCEED TO Section F. Otherwise, PROCEED TO Section C.

Section C. Selection of Method

56. All wetland delineation methods described in this manual can be grouped into two general types: routine and comprehensive. Routine determinations (Section D) involve simple, rapidly applied methods that result in sufficient qualitative data for making a determination. Comprehensive methods (Section E) usually require significant time and effort to obtain the needed quantitative data. The primary factor influencing method selection will usually be the complexity of the required determination. However, comprehensive methods may sometimes be selected for use in relatively simple determinations when rigorous documentation is required.

57. Three levels of routine wetland determinations are described below. Complexity of the project area and the quality and quantity of available information will influence the level selected for use.

a. *Level 1 - Onsite Inspection Unnecessary*. This level may be employed when the information already obtained (Section B) is sufficient for making a determination for the entire project area (see Section D, Subsection 1).

b. *Level 2 - Onsite Inspection Necessary.* This level must be employed when there is insufficient information already available to characterize the vegetation, soils, and hydrology of the entire project area (see Section D, Subsection 2).

c. *Level 3 - Combination of Levels 1 and 2.* This level should be used when there is sufficient information already available to characterize the vegetation, soils, and hydrology of a portion, but not all, of the project area. Methods described for Level 1 may be applied to portions of the area for which adequate information already exists, and onsite methods (Level 2) must be applied to the remainder of the area (see Section D, Subsection 3).

58. After considering all available information, select a tentative method (see above) for use, and PROCEED TO EITHER Section D or E, as appropriate. *NOTE: Sometimes it may be necessary to change to another method described in the manual, depending on the quality of available information and/or recent changes in the project area.*

Section D. Routine Determinations

59. This section describes general procedures for making routine wetland determinations. It is assumed that the user has already completed all applicable steps in Section B,[1] and a routine method has been tentatively selected for use (Section C). Subsections 1 through 3 describe steps to be followed when making a routine determination using one of the three levels described in Section C. Each subsection contains a flowchart that defines the relationship of steps to be used for that level of routine determinations. *NOTE: The selected method must be considered tentative because the user may be required to change methods during the determination.*

Subsection 1 - Onsite Inspection Unnecessary

60. This subsection describes procedures for making wetland determinations when sufficient information is already available (Section B) on which to base

[1] If it has been determined that it is more expedient to conduct an onsite inspection than to search for available information, complete STEPS 1 through 3 of Section B, and PROCEED TO Subsection 2.

the determination. A flowchart of required steps to be completed is presented in Figure 13, and each step is described below.

Equipment and materials

61. No special equipment is needed for applying this method. The following materials will be needed:

a. Map of project area (Section B, STEP 2).

b. Copies of DATA FORM 1 (Appendix B).

c. Appendices C and D to this manual.

Procedure

62. Complete the following steps, as necessary:

- *STEP 1 - Determine whether available data are sufficient for entire project area.* Examine the summarized data (Section B, STEPS 5, 7, and 9) and determine whether the vegetation, soils, and hydrology of the entire project area are adequately characterized. If so, PROCEED TO STEP 2. If all three parameters are adequately characterized for a portion, but not all, of the project area, PROCEED TO Subsection 3. If the vegetation, soils, and hydrology are not adequately characterized for any portion of the area, PROCEED TO Subsection 2.

- *STEP 2 - Determine whether hydrophytic vegetation is present.* Examine the vegetation data and list on DATA FORM 1 the dominant plant species found in each vegetation layer of each community type. *NOTE: A separate DATA FORM 1 will be required for each community type.* Record the indicator status for each dominant species ~~(Appendix C, Section 1 or 2)~~. When more than 50 percent of the dominant species in a plant community have an indicator status of OBL, FACW, and/or FAC,[1] hydrophytic vegetation is present. If one or more plant communities comprise hydrophytic vegetation, PROCEED TO STEP 3. If none of the plant communities comprise hydrophytic vegetation, none of the area is a wetland. Complete the vegetation section for each DATA FORM 1.

[1] For the FAC-neutral option, see paragraph 35*a*.

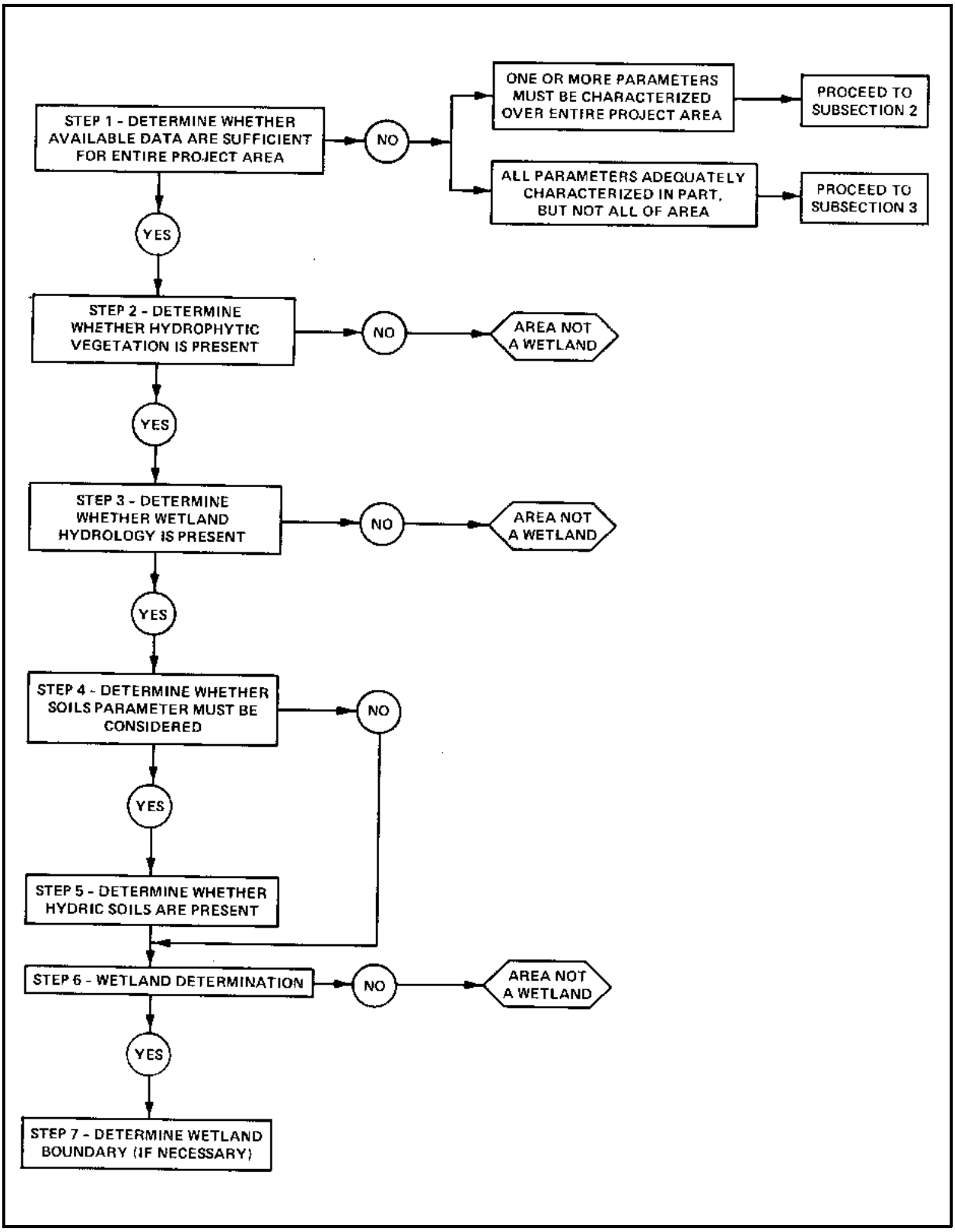


Figure 13. Flowchart of steps involved in making a wetland determination when an onsite inspection is unnecessary

- *STEP 3 - Determine whether wetland hydrology is present.* When one of the following conditions applies (STEP 2), it is only necessary to confirm that there has been no recent hydrologic alteration of the area:

    a. The entire project area is occupied by a plant community or communities in which all dominant species are OBL ~~(Appendix C, Section 1 or 2)~~.

    b. The project area contains two or more plant communities, all of which are dominated by OBL and/or FACW species, and the wetland-nonwetland boundary is abrupt[1] (e.g., a *Spartina alterniflora* marsh bordered by a road embankment).

  If either *a* or *b* applies, look for recorded evidence of recently constructed dikes, levees, impoundments, and drainage systems, or recent avalanches, mudslides, beaver dams, etc., that have significantly altered the area hydrology. If any significant hydrologic alteration is found, determine whether the area is still periodically inundated or has saturated soils for sufficient duration to support the documented vegetation (*a* or *b* above). When *a* or *b* applies and there is no evidence of recent hydrologic alteration, or when *a* or *b* do not apply and there is documented evidence that the area is periodically inundated or has saturated soils, wetland hydrology is present. Otherwise, wetland hydrology does not occur on the area. Complete the hydrology section of DATA FORM 1 and PROCEED TO STEP 4.

- *STEP 4 - Determine whether the soils parameter must be considered.* When either *a* or *b* of STEP 3 applies *and* there is either no evidence of recent hydrologic alteration of the project area or if wetland hydrology presently occurs on the area, hydric soils can be assumed to be present. If so, PROCEED TO STEP 6. Otherwise PROCEED TO STEP 5.

- *STEP 5 - Determine whether hydric soils are present.* Examine the soils data (Section B, STEP 7) and record the soil series or soil phase on DATA FORM 1 for each community type. Determine whether the soil is listed as a hydric soil ~~(Appendix D, Section 2)~~. If all community types have hydric soils, the entire project area has hydric soils. *(CAUTION: If the soil series description makes reference to inclusions of other soil types, data must be field verified).* Any portion of the area that lacks hydric soils is a nonwetland. Complete the soils section of each DATA FORM 1 and PROCEED TO STEP 6.

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[1] There must be documented evidence of periodic inundation or saturated soils when the project area: (a) has plant communities dominated by one or more FAC species; (b) has vegetation dominated by FACW species but no adjacent community dominated by OBL species; (c) has a gradual, nondistinct boundary between wetlands and nonwetlands; and/or (d) is known to have or is suspected of having significantly altered hydrology.

- *STEP 6 - Wetland determination.* Examine the DATA FORM 1 for each community type. Any portion of the project area is a wetland that has:

    a. Hydrophytic vegetation that conforms to one of the conditions identified in STEP 3*a* or 3*b* and has either no evidence of altered hydrology or confirmed wetland hydrology.

    b. Hydrophytic vegetation that does not conform to STEP 3*a* or 3*b*, has hydric soils, and has confirmed wetland hydrology.

    If STEP 6*a* or 6*b* applies to the entire project area, the entire area is a wetland. Complete a DATA FORM 1 for all plant community types. Portions of the area not qualifying as a wetland based on an office determination might or might not be wetlands. If the data used for the determination are considered to be highly reliable, portions of the area not qualifying as wetlands may properly be considered nonwetlands. PROCEED TO STEP 7. If the available data are incomplete or questionable, an onsite inspection (Subsection 2) will be required.

- *STEP 7 - Determine wetland boundary.* Mark on the base map all community types determined to be wetlands with a W and those determined to be nonwetlands with an N. Combine all wetland community types into a single mapping unit. The boundary of these community types is the interface between wetlands and nonwetlands.

Subsection 2 - Onsite Inspection Necessary

63. This subsection describes procedures for routine determinations in which the available information (Section B) is insufficient for one or more parameters. If only one or two parameters must be characterized, apply the appropriate steps and return to Subsection 1 and complete the determination. A flowchart of steps required for using this method is presented in Figure 14, and each step is described below.

Equipment and materials

64. The following equipment and materials will be needed:

a. Base map (Section B, STEP 2).

b. Copies of DATA FORM 1 (one for each community type and additional copies for boundary determinations).

c. Appendices C and D.

d. Compass.

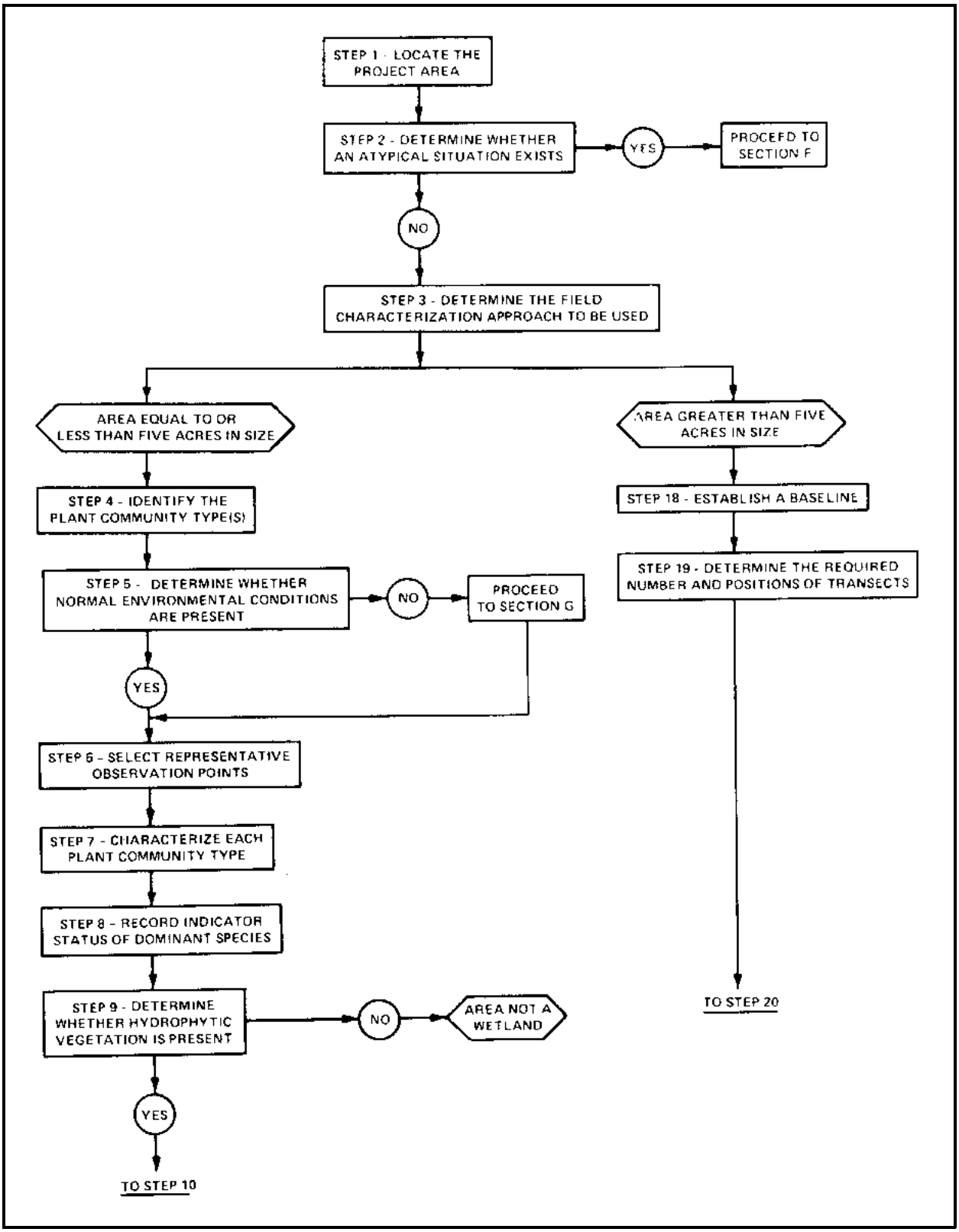


Figure 14. Flowchart of steps involved in making a routine wetland determination when an onsite visit is necessary (Continued)

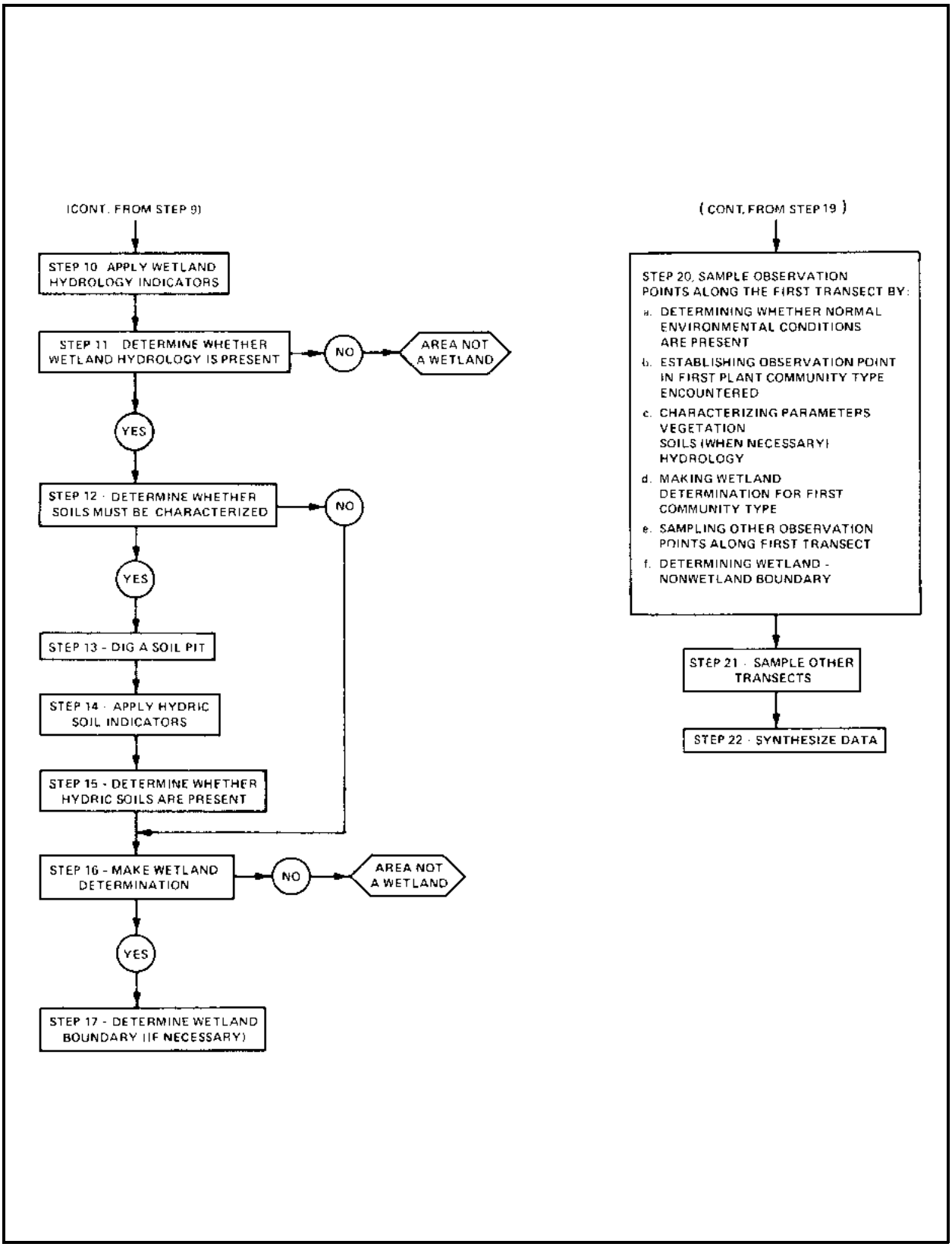


Figure 14. (Concluded)

e. Soil auger or spade (soils only).

f. Tape (300 ft).

g. Munsell Color Charts (Munsell Color 1975) (soils only).

Procedure

65. Complete the following steps, as necessary:

- *STEP 1 - Locate the project area.* Determine the spatial boundaries of the project area using information from a USGS quadrangle map or other appropriate map, aerial photography, and/or the project survey plan (when available). PROCEED TO STEP 2.

- *STEP 2 - Determine whether an atypical situation exists.* Examine the area and determine whether there is evidence of sufficient natural or human-induced alteration to significantly alter the area vegetation, soils, and/or hydrology. *NOTE: Include possible offsite modifications that may affect the area hydrology.* If not, PROCEED TO STEP 3.

  If one or more parameters have been significantly altered by an activity that would normally require a permit, PROCEED TO Section F and determine whether there is sufficient evidence that hydrophytic vegetation, hydric soils, and/or wetland hydrology were present prior to this alteration. Then, return to this subsection and characterize parameters not significantly influenced by human activities. PROCEED TO STEP 3.

- *STEP 3 - Determine the field characterization approach to be used.* Considering the size and complexity of the area, determine the field characterization approach to be used. When the area is equal to or less than 5 acres in size (Section B, STEP 3) and the area is thought to be relatively homogeneous with respect to vegetation, soils, and/or hydrologic regime, PROCEED TO STEP 4. When the area is greater than 5 acres in size (Section B, STEP 3) or appears to be highly diverse with respect to vegetation, PROCEED TO STEP 18.

Areas Equal To or Less Than 5 Acres in Size

- *STEP 4 - Identify the plant community type(s).* Traverse the area and determine the number and locations of plant community types. Sketch the location of each on the base map (Section B, STEP 2), and give each community type a name. PROCEED TO STEP 5.

- *STEP 5 - Determine whether normal environmental conditions are present.* Determine whether normal environmental conditions are present by considering the following:

    a. Is the area presently lacking hydrophytic vegetation or hydrologic indicators due to annual or seasonal fluctuations in precipitation or ground-water levels?

    b. Are hydrophytic vegetation indicators lacking due to seasonal fluctuations in temperature?

  If the answer to either of these questions is thought to be YES, PROCEED TO Section G. If the answer to both questions is NO, PROCEED TO STEP 6.

- *STEP 6 - Select representative observation points.* Select a representative observation point in each community type. A representative observation point is one in which the apparent characteristics (determine visually) best represent characteristics of the entire community. Mark on the base map the approximate location of the observation point. PROCEED TO STEP 7.

- *STEP 7 - Characterize each plant community type.* Visually determine the dominant plant species in each vegetation layer of each community type and record them on DATA FORM 1 (use a separate DATA FORM 1 for each community type). Dominant species are those having the greatest relative basal area (woody overstory),[1] greatest height (woody understory), greatest percentage of areal cover (herbaceous understory), and/or greatest number of stems (woody vines). PROCEED TO STEP 8.

- *STEP 8 - Record indicator status of dominant species.* Record on DATA FORM 1 the indicator status ~~(Appendix C, Section 1 or 2)~~ of each dominant species in each community type. PROCEED TO STEP 9.

- *STEP 9 - Determine whether hydrophytic vegetation is present.* Examine each DATA FORM 1. When more than 50 percent of the dominant species in a community type have an indicator status (STEP 8) of OBL, FACW, and/or FAC,[2] hydrophytic vegetation is present. Complete the vegetation section of each DATA FORM 1. Portions of the area failing this test are not wetlands. PROCEED TO STEP 10.

- *STEP 10 - Apply wetland hydrologic indicators.* Examine the portion of the area occupied by each plant community type for positive indicators

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[1] This term is used because species having the largest individuals may not be dominant when only a few are present. To determine relative basal area, consider both the size and number of individuals of a species and subjectively compare with other species present.

[2] For the FAC-neutral option, see paragraph 35*a*.

of wetland hydrology (Part III, paragraph 49). Record findings on the appropriate DATA FORM 1. PROCEED TO STEP 11.

- *STEP 11 - Determine whether wetland hydrology is present.* Examine the hydrologic information on DATA FORM 1 for each plant community type. Any portion of the area having a positive wetland hydrology indicator has wetland hydrology. If positive wetland hydrology indicators are present in all community types, the entire area has wetland hydrology. If no plant community type has a wetland hydrology indicator, none of the area has wetland hydrology. Complete the hydrology portion of each DATA FORM 1. PROCEED TO STEP 12.

- *STEP 12 - Determine whether soils must be characterized.* Examine the vegetation section of each DATA FORM 1. Hydric soils are assumed to be present in any plant community type in which:

    a. All dominant species have an indicator status of OBL.

    b. All dominant species have an indicator status of OBL or FACW, and the wetland boundary (when present) is abrupt.[1]

  When either *a* or *b* occurs and wetland hydrology is present, check the hydric soils blank as positive on DATA FORM 1 and PROCEED TO STEP 16. If neither *a* nor *b* applies, PROCEED TO STEP 13.

- *STEP 13 - Dig a soil pit.* Using a soil auger or spade, dig a soil pit at the representative location in each community type. The procedure for digging a soil pit is described in Appendix D, Section 1. When completed, approximately 16 inches of the soil profile will be available for examination. PROCEED TO STEP 14.

- *STEP 14 - Apply hydric soil indicators.* Examine the soil at each location and compare its characteristics immediately below the A-horizon or 10 inches (whichever is shallower) with the hydric soil indicators described in Part III, paragraph 44 and/or 45. Record findings on the appropriate DATA FORM 1's. PROCEED TO STEP 15.

- *STEP 15 - Determine whether hydric soils are present.* Examine each DATA FORM 1 and determine whether a positive hydric soil indicator was found. If so, the area at that location has hydric soil. If soils at all sampling locations have positive hydric soil indicators, the entire area has hydric soils. If soils at all sampling locations lack positive hydric soil indicators, none of the area is a wetland. Complete the soil section of each DATA FORM 1. PROCEED TO STEP 16.

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[1] The soils parameter must be considered in any plant community in which: (a) the community is dominated by one or more FAC species; (b) no community type dominated by OBL species is present; (c) the boundary between wetlands and nonwetlands is gradual or nondistinct; (d) the area is known to or is suspected of having significantly altered hydrology.

- *STEP 16 - Make wetland determination.* Examine DATA FORM 1. If the entire area presently or normally has wetland indicators of all three parameters (STEPS 9, 11, and 15), the entire area is a wetland. If the entire area presently or normally lacks wetland indicators of one or more parameters, the entire area is a nonwetland. If only a portion of the area presently or normally has wetland indicators for all three parameters, PROCEED TO STEP 17.

- *STEP 17 - Determine wetland-nonwetland boundary.* Mark each plant community type on the base map with a W if wetland or an N if non-wetland. Combine all wetland plant communities into one mapping unit and all nonwetland plant communities into another mapping unit. The wetland-nonwetland boundary will be represented by the interface of these two mapping units.

Areas Greater Than 5 Acres in Size

- *STEP 18 - Establish a baseline.* Select one project boundary as a baseline. The baseline should parallel the major watercourse through the area or should be perpendicular to the hydrologic gradient (Figure 15). Determine the approximate baseline length. PROCEED TO STEP 19.

- *STEP 19 - Determine the required number and position of transects.* Use the following to determine the required number and position of transects (specific site conditions may necessitate changes in intervals):

Baseline Length, Miles	Number of Required Transects
≤0.25	3
>0.25 - 0.50	3
>0.50 - 0.75	3
>0.75 - 1.00	3
>1.00 - 2.00	3-5
>2.00 - 4.00	5-8
>4.00	8 or more[1]

[1] Transect intervals should not exceed 0.5 mile.

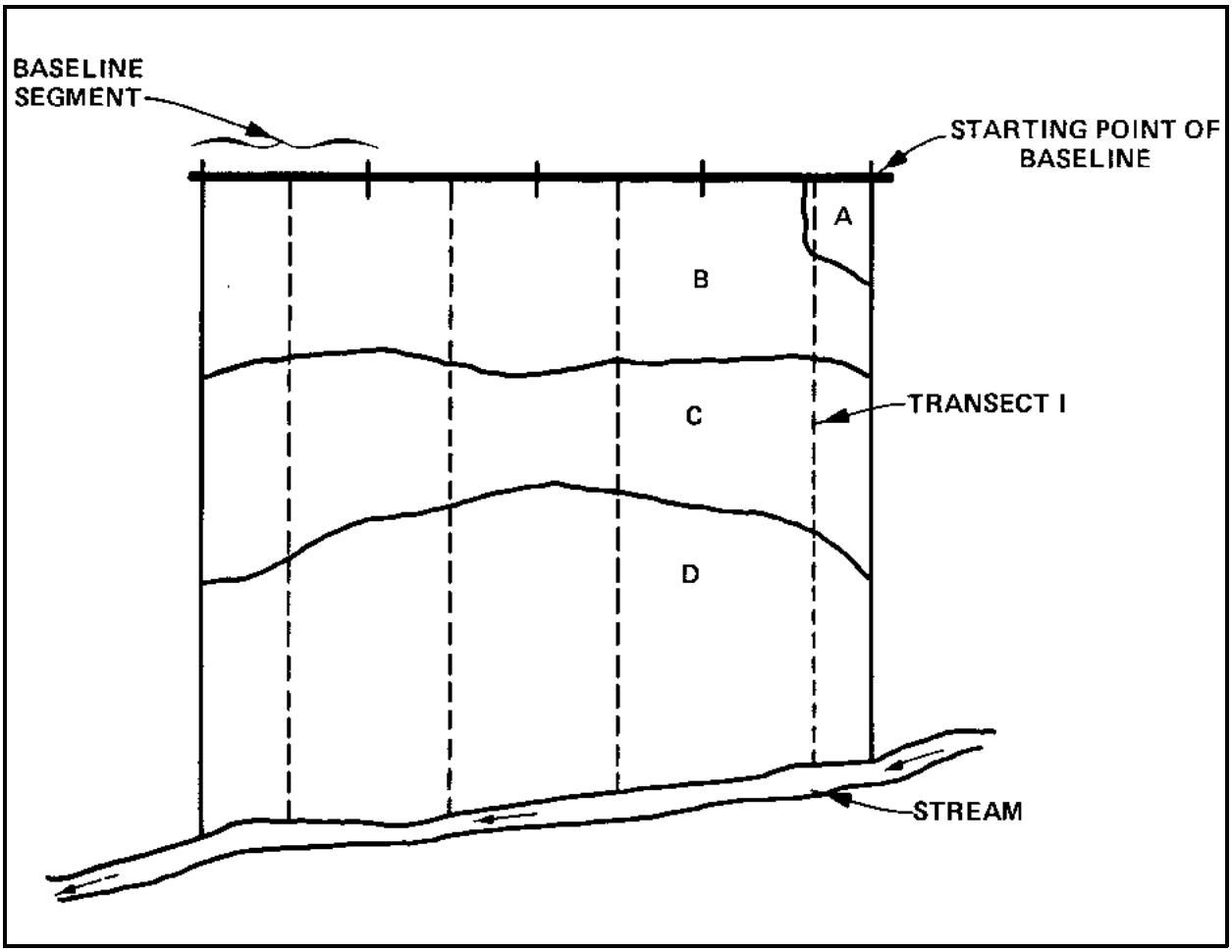


Figure 15. General orientation of baseline and transects (dotted lines) in a hypothetical project area. Alpha characters represent different plant communities. All transects start at the midpoint of a baseline segment except the first, which was repositioned to include community type A

Divide the baseline length by the number of required transects. Establish one transect in each resulting baseline increment. Use the midpoint of each baseline increment as a transect starting point. For example, if the baseline is 1,200 ft in length, three transects would be established—one at 200 ft, one at 600 ft, and one at 1,000 ft from the baseline starting point. *CAUTION: All plant community types must be included. This may necessitate relocation of one or more transect lines. PROCEED TO STEP 20.*

- *STEP 20 - Sample observation points along the first transect.* Beginning at the starting point of the first transect, extend the transect at a 90-deg angle to the baseline. Use the following procedure as appropriate to simultaneously characterize the parameters at each observation point. Combine field-collected data with information already available and make a wetland determination at each observation point. A DATA FORM 1 must be completed for each observation point.

a. *Determine whether normal environmental conditions are present.* Determine whether normal environmental conditions are present by considering the following:

(1) Is the area presently lacking hydrophytic vegetation and/or hydrologic indicators due to annual or seasonal fluctuations in precipitation or ground-water levels?

(2) Are hydrophytic vegetation indicators lacking due to seasonal fluctuations in temperature?

If the answer to either of these questions is thought to be YES, PROCEED TO Section G. If the answer to both questions is NO, PROCEED TO STEP 20*b*.

b. *Establish an observation point in the first plant community type encountered.* Select a representative location along the transect in the first plant community type encountered. When the first plant community type is large and covers a significant distance along the transect, select an area that is no closer than 300 ft to a perceptible change in plant community type. PROCEED TO STEP 20*c*.

c. *Characterize parameters.* Characterize the parameters at the observation point by completing (1), (2), and (3) below:

(1) *Vegetation.* Record on DATA FORM 1 the dominant plant species in each vegetation layer occurring in the immediate vicinity of the observation point. Use a 5-ft radius for herbs and saplings/shrubs, and a 30-ft radius for trees and woody vines (when present). Subjectively determine the dominant species by estimating those having the largest relative basal area[1] (woody overstory), greatest height (woody understory), greatest percentage of areal cover (herbaceous understory), and/or greatest number of stems (woody vines). *NOTE: Plot size may be estimated, and plot size may also be varied when site conditions warrant.* Record on DATA FORM 1 any dominant species observed to have morphological adaptations (Appendix C, Section 3) for occurrence in wetlands, and determine and record dominant species that have known physiological adaptations for occurrence in wetlands (Appendix C, Section 3). Record on DATA FORM 1 the indicator status ~~(Appendix C, Section 1 or 2)~~ of each dominant species. Hydrophytic

[1] This term is used because species having the largest individuals may not be dominant when only a few are present. To use relative basal area, consider both the size and number of individuals of a species and subjectively compare with other species present.

vegetation is present at the observation point when more than 50 percent of the dominant species have an indicator status of OBL, FACW, and/or FAC;[1] when two or more dominant species have observed morphological or known physiological adaptations for occurrence in wetlands; or when other indicators of hydrophytic vegetation (Part III, paragraph 35) are present. Complete the vegetation section of DATA FORM 1. PROCEED TO (2).

(2) *Soils.* In some cases, it is not necessary to characterize the soils. Examine the vegetation of DATA FORM 1. Hydric soils can be assumed to be present when:

(a) All dominant plant species have an indicator status of OBL.

(b) All dominant plant species have an indicator status of OBL and/or FACW (at least one dominant species must be OBL).[2]

When either (a) or (b) applies, check the hydric soils blank as positive and PROCEED TO (3). If neither (a) nor (b) applies but the vegetation qualifies as hydrophytic, dig a soil pit at the observation point using the procedure described in Appendix D, Section 1. Examine the soil immediately below the A-horizon or 10-inches (whichever is shallower) and compare its characteristics (Appendix D, Section 1) with the hydric soil indicators described in Part III, paragraph 44 and/or 45. Record findings on DATA FORM 1. If a positive hydric soil indicator is present, the soil at the observation point is a hydric soil. If no positive hydric soil indicator is found, the area at the observation point does not have hydric soils and the area at the observation point is not a wetland. Complete the soils section of DATA FORM 1 for the observation point. PROCEED TO (3) if hydrophytic vegetation (1) and hydric soils (2) are present. Otherwise, PROCEED TO STEP 20*d*.

(3) *Hydrology*. Examine the observation point for indicators of wetland hydrology (Part III, paragraph 49) and record observations on DATA FORM 1. Consider the indicators in the same sequence as presented in Part III, paragraph 49. If a positive wetland hydrology indicator

[1] For the FAC-neutral option, see paragraph 35*a*.
[2] Soils must be characterized when any dominant species has an indicator status of FAC.

is present, the area at the observation point has wetland hydrology. If no positive wetland hydrologic indicator is present, the area at the observation point is not a wetland. Complete the hydrology section of DATA FORM 1 for the observation point. PROCEED TO STEP 20*d*.

d. *Wetland determination.* Examine DATA FORM 1 for the observation point. Determine whether wetland indicators of all three parameters are or would normally be present during a significant portion of the growing season. If so, the area at the observation point is a wetland. If no evidence can be found that the area at the observation point normally has wetland indicators for all three parameters, the area is a nonwetland. PROCEED TO STEP 20*e*.

e. *Sample other observation points along the first transect.* Continue along the first transect until a different community type is encountered. Establish a representative observation point within this community type and repeat STEP 20*c* and 20*d*. If the areas at both observation points are either wetlands or nonwetlands, continue along the transect and repeat STEP 20*c* and 20*d* for the next community type encountered. Repeat for all other community types along the first transect. If the area at one observation point is wetlands and the next observation point is nonwetlands (or vice versa), PROCEED TO STEP 20*f*.

f. *Determine wetland-nonwetland boundary.* Proceed along the transect from the wetland observation point toward the nonwetland observation point. Look for subtle changes in the plant community (e.g., the first appearance of upland species, disappearance of apparent hydrology indicators, or slight changes in topography). When such features are noted, establish an observation point and repeat the procedures described in STEP 20*c* through 20*d*. *NOTE: A new DATA FORM 1 must be completed for this observation point, and all three parameters must be characterized by field observation.* If the area at this observation point is a wetland, proceed along the transect toward the nonwetland observation point until upland indicators are more apparent. Repeat the procedures described in STEP 20*c* through 20*d*. If the area at this observation point is a nonwetland, move halfway back along the transect toward the last documented wetland observation point and repeat the procedure described in STEP 20*c* through 20*d*. Continue this procedure until the wetland-nonwetland boundary is found. It is not necessary to complete a DATA FORM 1 for all intermediate points, but a DATA FORM 1 should be completed for the wetland-nonwetland boundary. Mark the position of the wetland boundary on the base map, and continue along the first transect until all community types have been sampled and

all wetland boundaries located. *CAUTION: In areas where wetlands are interspersed among nonwetlands (or vice versa), several boundary determinations will be required.* When all necessary wetland determinations have been completed for the first transect, PROCEED TO STEP 21.

- *STEP 21 - Sample other transects.* Repeat procedures described in STEP 21 for all other transects. When completed, a wetland determination will have been made for one observation point in each community type along each transect, and all wetland-nonwetland boundaries along each transect will have been determined. PROCEED TO STEP 22.

- *STEP 22 - Synthesize data.* Examine all completed copies of DATA FORM 1, and mark each plant community type on the base map. Identify each plant community type as either a wetland (W) or nonwetland (N). If all plant community types are identified as wetlands, the entire area is wetlands. If all plant community types are identified as nonwetlands, the entire area is nonwetlands. If both wetlands and nonwetlands are present, identify observation points that represent wetland boundaries on the base map. Connect these points on the map by generally following contour lines to separate wetlands from nonwetlands. Walk the contour line between transects to confirm the wetland boundary. Should anomalies be encountered, it will be necessary to establish short transects in these areas, apply the procedures described in STEP 20*f*, and make any necessary adjustments on the base map.

Subsection 3 - Combination of Levels I and 2

66. In some cases, especially for large projects, adequate information may already be available (Section B) to enable a wetland determination for a portion of the project area, while an onsite visit will be required for the remainder of the area. Since procedures for each situation have already been described in Subsections 1 and 2, they will not be repeated. Apply the following steps:

- *STEP 1 - Make wetland determination for portions of the project area that are already adequately characterized.* Apply procedures described in Subsection 1. When completed, a DATA FORM 1 will have been completed for each community type, and a map will have been prepared identifying each community type as wetland or nonwetland and showing any wetland boundary occurring in this portion of the project area. PROCEED TO STEP 2.

- *STEP 2 - Make wetland determination for portions of the project area that require an onsite visit.* Apply procedures described in Subsection 2. When completed, a DATA FORM 1 will have been completed for each plant community type or for a number of observation points (including

wetland boundary determinations). A map of the wetland (if present) will also be available. PROCEED TO STEP 3.

- *STEP 3 - Synthesize data.* Using the maps resulting from STEPS 1 and 2, prepare a summary map that shows the wetlands of the entire project area. *CAUTION: Wetland boundaries for the two maps will not always match exactly. When this occurs, an additional site visit will be required to refine the wetland boundaries. Since the degree of resolution of wetland boundaries will be greater when determined onsite, it may be necessary to employ procedures described in Subsection 2 in the vicinity of the boundaries determined from Subsection 1 to refine these boundaries.*

Section E. Comprehensive Determinations

67. This section describes procedures for making comprehensive wetland determinations. Unlike procedures for making routine determinations (Section D), application of procedures described in this section will result in maximum information for use in making determinations, and the information usually will be quantitatively expressed. Comprehensive determinations should only be used when the project area is very complex and/or when the determination requires rigorous documentation. This type of determination may be required in areas of any size, but will be especially useful in large areas. There may be instances in which only one parameter (vegetation, soil, or hydrology) is disputed. In such cases, only procedures described in this section that pertain to the disputed parameter need be completed. It is assumed that the user has already completed all applicable steps in Section B. *NOTE: Depending on site characteristics, it may be necessary to alter the sampling design and/or data collection procedures.*

68. This section is divided into five basic types of activities. The first consists of preliminary field activities that must be completed prior to making a determination (STEPS 1 through 5). The second outlines procedures for determining the number and locations of required determinations (STEPS 6 through 8). The third describes the basic procedure for making a comprehensive wetland determination at any given point (STEPS 9 through 17). The fourth describes a procedure for determining wetland boundaries (STEP 18). The fifth describes a procedure for synthesizing the collected data to determine the extent of wetlands in the area (STEPS 20 and 21). A flowchart showing the relationship of various steps required for making a comprehensive determination is presented in Figure 16.

Equipment and materials

69. Equipment and materials needed for making a comprehensive determination include:

a. Base map (Section B, STEP 2).

b. Copies of DATA FORMS 1 and 2.

c. Appendices C and D.

d. Compass.

e. Tape (300 ft).

f. Soil auger or spade.

g. Munsell Color Charts (Munsell Color 1975).

h. Quadrat (3.28 ft by 3.28 ft).

i. Diameter or basal area tape (for woody overstory).

Field procedures

70. Complete the following steps:

- *STEP 1 - Identify the project area.* Using information from the USGS quadrangle or other appropriate map (Section B), locate and measure the spatial boundaries of the project area. Determine the compass heading of each boundary and record on the base map (Section B, STEP 2). The applicant's survey plan may be helpful in locating the project boundaries. PROCEED TO STEP 2.

- *STEP 2 - Determine whether an atypical situation exists.* Examine the area and determine whether there is sufficient natural or human-induced alteration to significantly change the area vegetation, soils, and/or hydrology. If not, PROCEED TO STEP 3. If one or more parameters have been recently altered significantly, PROCEED TO Section F and determine whether there is sufficient evidence that hydrophytic vegetation, hydric soils, and/or wetland hydrology were present on the area prior to alteration. Then return to this section and characterize parameters not significantly influenced by human activities. PROCEED TO STEP 3.

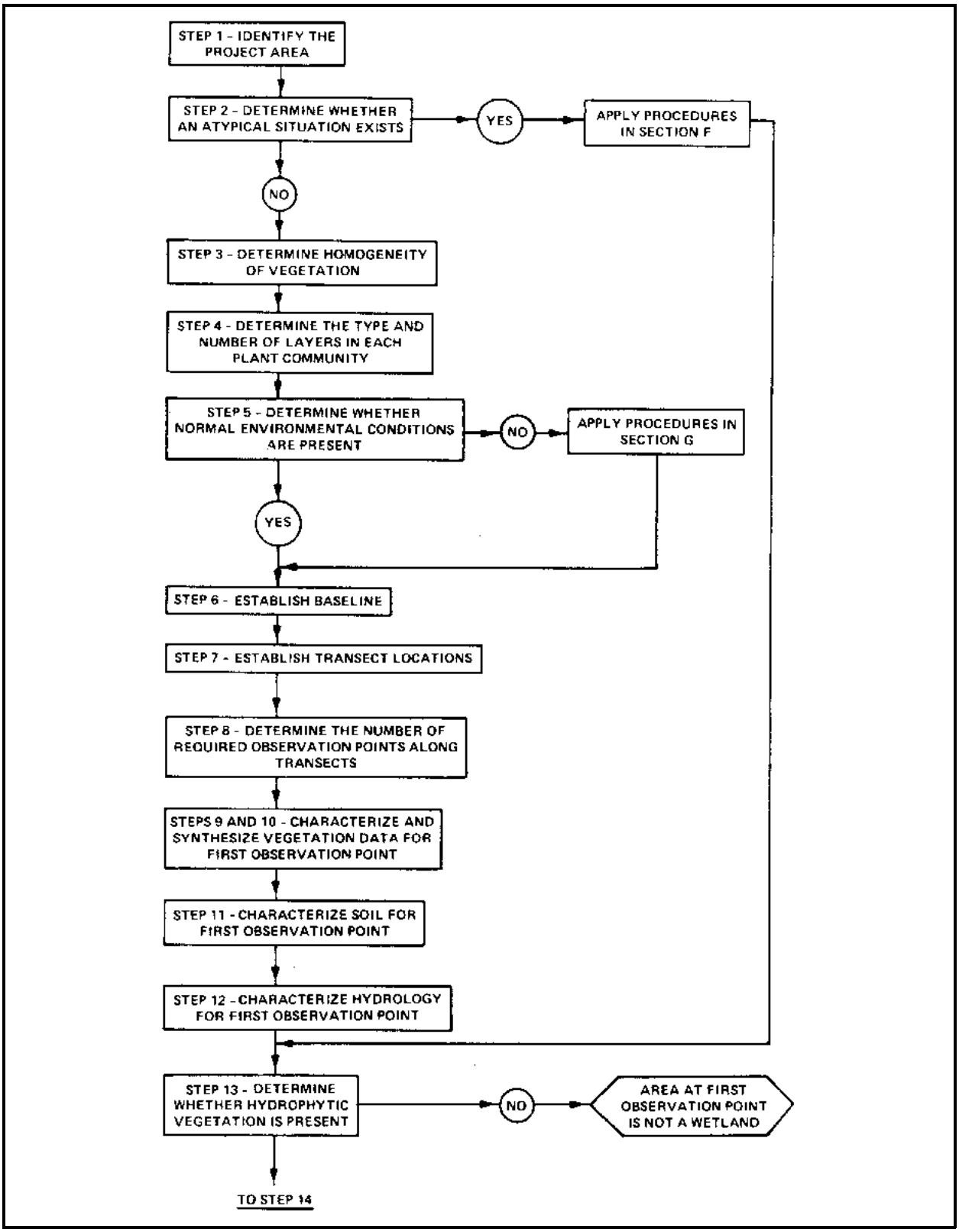


Figure 16. Flowchart of steps involved in making a comprehensive wetland determination (Section E) (Continued)

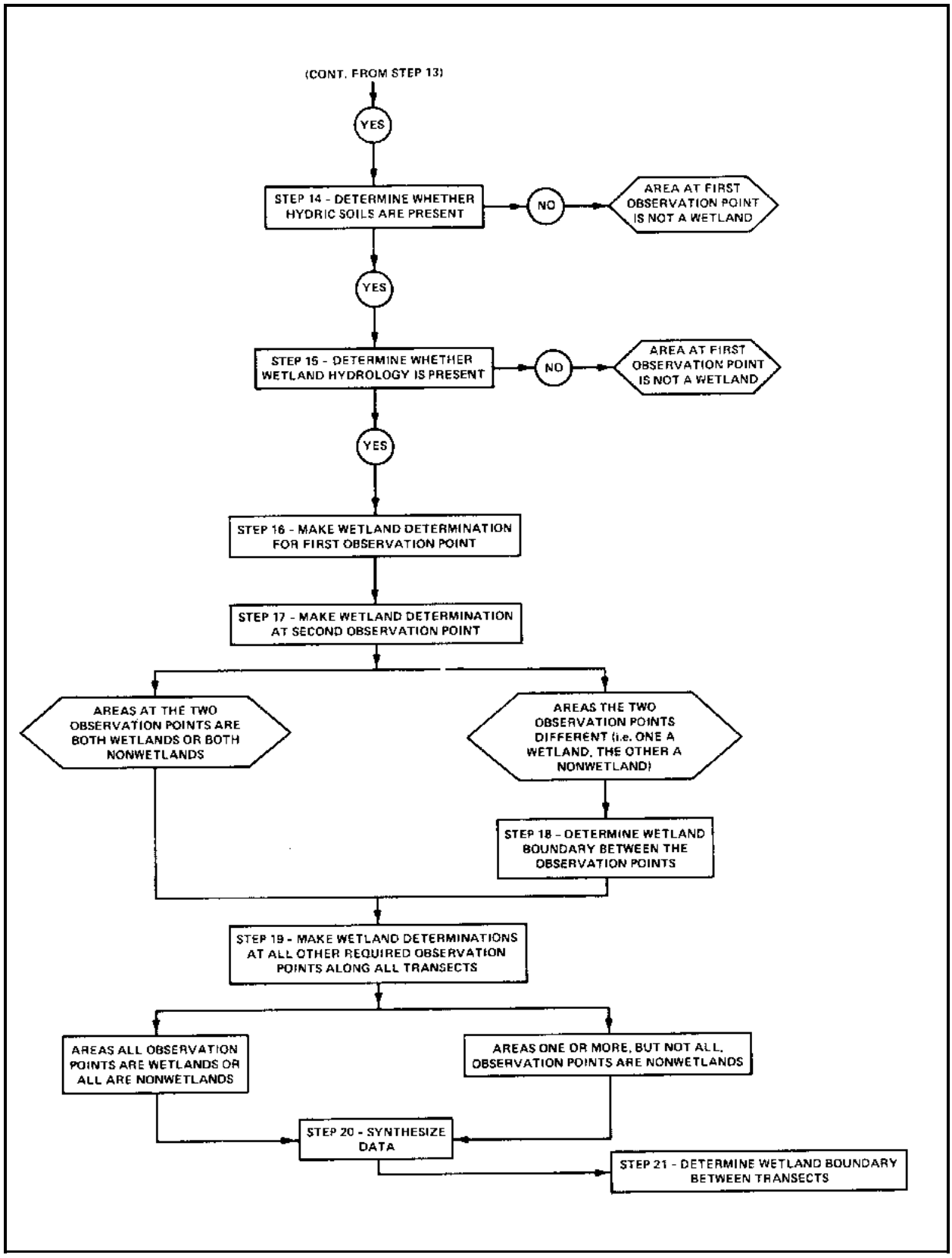


Figure 16. (Concluded)

- *STEP 3 - Determine homogeneity of vegetation.* While completing STEP 2, determine the number of plant community types present. Mark the approximate location of each community type on the base map. The number and locations of required wetland determinations will be strongly influenced by both the size of the area and the number and distribution of plant community types; the larger the area and greater the number of plant community types, the greater the number of required wetland determinations. It is imperative that all plant community types occurring in all portions of the area be included in the investigation. PROCEED TO STEP 4.

- *STEP 4 - Determine the type and number of layers in each plant community.* Examine each identified plant community type and determine the type(s) and number of layers in each community. Potential layers include trees (woody overstory), saplings/shrubs (woody understory), herbs (herbaceous understory), and/or woody vines. PROCEED TO STEP 5.

- *STEP 5 - Determine whether normal environmental conditions are present.* Determine whether normal environmental conditions are present at the observation point by considering the following:

    a. Is the area at the observation point presently lacking hydrophytic vegetation and/or hydrologic indicators due to annual or seasonal fluctuations in precipitation or groundwater levels?

    b. Are hydrophytic vegetation indicators lacking due to seasonal fluctuations in temperature?

    If the answer to either of these questions is thought to be YES, PROCEED TO Section G. If the answer to both questions is NO, PROCEED TO STEP 6.

- *STEP 6 - Establish a baseline.* Select one project boundary area as a baseline. The baseline should extend parallel to any major watercourse and/or perpendicular to a topographic gradient (see Figure 17). Determine the baseline length and record on the base map both the baseline length and its compass heading. PROCEED TO STEP 7.

- *STEP 7 - Establish transect locations.* Divide the baseline into a number of equal segments (Figure 17). Use the following as a guide to determine the appropriate number of baseline segments:

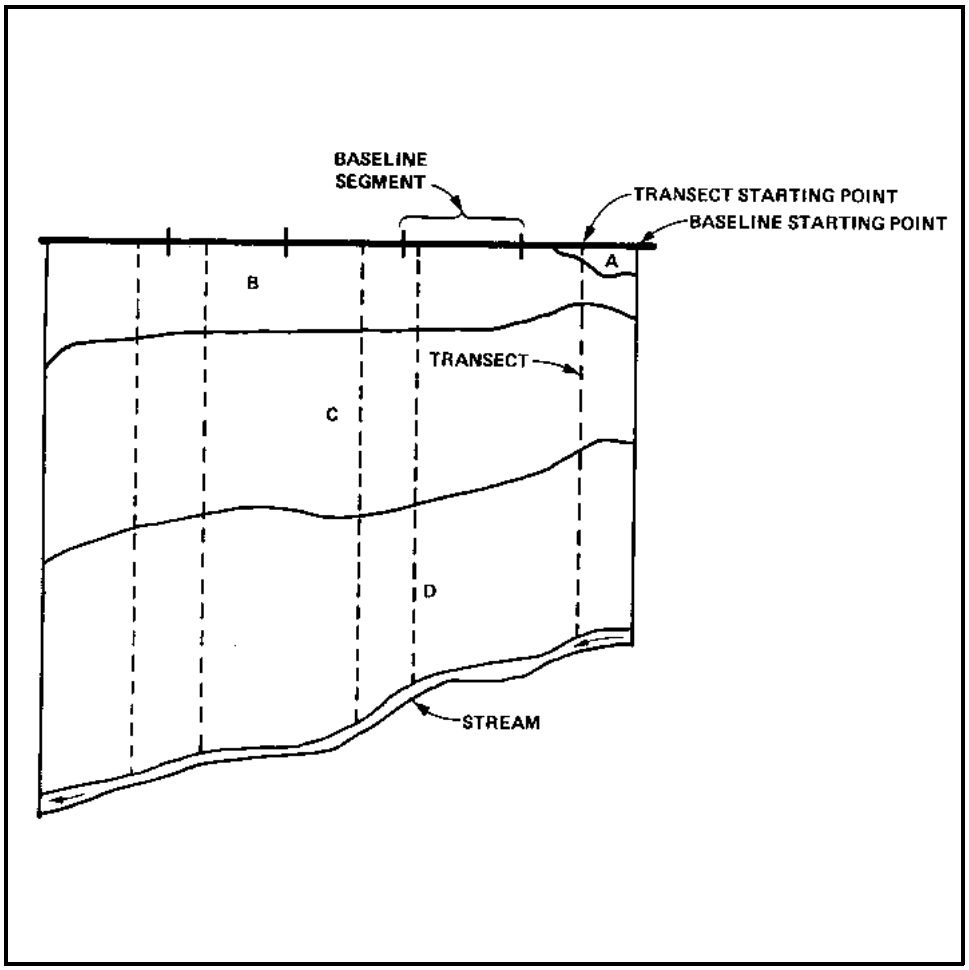


Figure 17. General orientation of baseline and transects in a hypothetical project area. Alpha characters represent different plant communities. Transect positions were determined using a random numbers table

Baseline Length, ft	Number of Segments	Length of Baseline Segment, ft
>50 - 500	3	18 - 167
>500 - 1,000	3	167 - 333
>1,000 - 5,000	5	200 - 1,000
>5,000 - 10,000	7	700 - 1,400
>10,000[1]	Variable	2,000

[1] If the baseline exceeds 5 miles, baseline segments should be 0.5 mile in length.

Use a random numbers table or a calculator with a random numbers generation feature to determine the position of a transect starting point within each baseline segment. For example, when the baseline is 4,000 ft, the number of baseline segments will be five, and the baseline segment length will be 4,000/5 = 800 ft. Locate the first transect within the first 800 ft of the baseline. If the random numbers table yields 264 as the

distance from the baseline starting point, measure 264 ft from the baseline starting point and establish the starting point of the first transect. If the second random number selected is 530, the starting point of the second transect will be located at a distance of 1,330 ft (800 + 530 ft) from the baseline starting point. *CAUTION: Make sure that each plant community type is included in at least one transect. If not, modify the sampling design accordingly.* When the starting point locations for all required transects have been determined, PROCEED TO STEP 8.

- *STEP 8 - Determine the number of required observation points along transects.* The number of required observation points along each transect will be largely dependent on transect length. Establish observation points along each transect using the following as a guide:

Transect Length, ft	Number of Observation Points	Interval Between Observation Points, ft
<1,000	2-10	100
1,000 - <5,000	10	100 - 500
5,000 - <10,000	10	500 - 1,000
≥ 10,000	>10	1,000

Establish the first observation point at a distance of 50 ft from the baseline (Figure 17). When obvious nonwetlands occupy a long portion of the transect from the baseline starting point, establish the first observation point in the obvious nonwetland at a distance of approximately 300 ft from the point that the obvious nonwetland begins to intergrade into a potential wetland community type. Additional observation points must also be established to determine the wetland boundary between successive regular observation points when one of the points is a wetland and the other is a nonwetland. *CAUTION: In large areas having a mosaic of plant community types, several wetland boundaries may occur along the same transect.* PROCEED TO STEP 9 and apply the comprehensive wetland determination procedure at each required observation point. Use the described procedure to simultaneously characterize the vegetation, soil, and hydrology at each required observation point along each transect, and use the resulting characterization to make a wetland determination at each point. *NOTE: ALL required wetland boundary determinations should be made while proceeding along a transect.*

- *STEP 9 - Characterize the vegetation at the first observation point along the first transect.*[1] Record on DATA FORM 2 the vegetation occurring

[1] There is no single best procedure for characterizing vegetation. Methods described in STEP 9 afford standardization of the procedure. However, plot size and descriptors for determining dominance may vary.

at the first observation point along the first transect by completing the following (as appropriate):

a. *Trees.* Identify each tree occurring within a 30-ft radius[1] of the observation point, measure its basal area (square inches) or diameter at breast height (DBH) using a basal area tape or diameter tape, respectively, and record. *NOTE: If DBH is measured, convert values to basal area by applying the formula* $A = \pi r^2$. *This must be done on an individual basis.* A tree is any nonclimbing, woody plant that has a DBH of ≥ 3.0 in., regardless of height.

b. *Saplings/shrubs.* Identify each sapling/shrub occurring within a 10-ft radius of the observation point, estimate its height, and record the midpoint of its class range using the following height classes (height is used as an indication of dominance; taller individuals exert a greater influence on the plant community):

Height Class	Height Class Range, ft	Midpoint of Range, ft
1	1-3	2
2	3-5	4
3	5-7	6
4	7-9	8
5	9-11	10
6	>11	12

A sapling/shrub is any woody plant having a height >3.2 ft but a stem diameter of <3.0 in., exclusive of woody vines.

c. *Herbs.* Place a 3.28- by 3.28-ft quadrat with one corner touching the observation point and one edge adjacent to the transect line. As an alternative, a 1.64-ft-radius plot with the center of the plot representing the observation point position may be used. Identify each plant species with foliage extending into the quadrat and estimate its percent cover by applying the following cover classes:

[1] A larger sampling plot may be necessary when trees are large and widely spaced.

Cover Class	Class Range, Percent	Midpoint of Class Range, Percent
1	0-5	2.5
2	>5-25	15.0
3	>25-50	37.5
4	>50-75	62.5
5	>75-95	85.0
6	>95-100	97.5

Include all nonwoody plants and woody plants <3.2 ft in height. *NOTE: Total percent cover for all species will often exceed 100 percent.*

d. *Woody vines (lianas).* Identify species of woody vines climbing each tree and sapling/shrub sampled in STEPS 9*a* and 9*b* above, and record the number of stems of each. Since many woody vines branch profusely, count or estimate the number of stems at the ground surface. Include only individuals rooted in the 10-ft radius plot. Do not include individuals <3.2 ft in height. PROCEED TO STEP 10.

- *STEP 10 - Analyze field vegetation data.* Examine the vegetation data (STEP 9) and determine the dominant species in each vegetation layer[1] by completing the following:

a. *Trees.* Obtain the total basal area (square inches) for each tree species identified in STEP 9*a* by summing the basal area of all individuals of a species found in the sample plot. Rank the species in descending order of dominance based on total basal area. Complete DATA FORM 2 for the tree layer.

b. *Saplings/shrubs.* Obtain the total height for each sapling/shrub species identified in STEP 9*b*. Total height, which is an estimate of dominance, is obtained by summing the midpoints of height classes for all individuals of a species found in the sample plot. Rank the species in descending order of dominance based on sums of midpoints of height class ranges. Complete DATA FORM 2 for the sapling/shrub layer.

c. *Herbs.* Obtain the total cover for each herbaceous and woody seedling species identified in STEP 9*c*. Total cover is obtained by using the midpoints of the cover class range as-

[1] The same species may occur as a dominant in more than one vegetation layer.

signed to each species (only one estimate of cover is made for a species in a given plot). Rank herbs and woody seedlings in descending order of dominance based on percent cover. Complete DATA FORM 2 for the herbaceous layer.

d. *Woody vines (lianas).* Obtain the total number of individuals of each species of woody vine identified in STEP 9*d*. Rank the species in descending order of dominance based on number of stems. Complete DATA FORM 2 for the woody vine layer. PROCEED TO STEP 11.

- *STEP 11 - Characterize soil.* If a soil survey is available (Section B), the soil type may already be known. Have a soil scientist confirm that the soil type is correct, and determine whether the soil series is a hydric soil ~~(Appendix D, Section 2)~~. *CAUTION: Mapping units on soil surveys sometimes have inclusions of soil series or phases not shown on the soil survey map.* If a hydric soil type is confirmed, record on DATA FORM 1 and PROCEED TO STEP 12. If not, dig a soil pit using a soil auger or spade (See Appendix D, Section 1) and look for indicators of hydric soils immediately below the A-horizon or 10 inches (whichever is shallower) (Part III, paragraphs 44 and/or 45). Record findings on DATA FORM 1. PROCEED TO STEP 12.

- *STEP 12 - Characterize hydrology.* Examine the observation point for indicators of wetland hydrology (Part III, paragraph 49) and record observations on DATA FORM 1. Consider indicators in the same sequence as listed in paragraph 49. PROCEED TO STEP 13.

- *STEP 13 - Determine whether hydrophytic vegetation is present.* Record the three dominant species from each vegetation layer (five species if only one or two layers are present) on DATA FORM 1.[1] Determine whether these species occur in wetlands by considering the following:

  a. *More than 50 percent of the dominant plant species are OBL, FACW, and/or FAC[2] on lists of plant species that occur in wetlands.* Record the indicator status of all dominant species ~~(Appendix C, Section 1 or 2)~~ on DATA FORM 1. Hydrophytic vegetation is present when the majority of the dominant species have an indicator status of OBL, FACW, or FAC. *CAUTION: Not necessarily all plant communities composed of only FAC species are hydrophytic communities. They are hydrophytic communities only when positive indicators of hydric soils and wetland hydrology are also found.* If this indicator is satisfied, complete the vegetation portion of

[1] Record all dominant species when less than three are present in a vegetation layer.
[2] For the FAC-neutral option, see paragraph 35*a*.

DATA FORM 1 and PROCEED TO STEP 14. If not, consider other indicators of hydrophytic vegetation.

b. *Presence of adaptations for occurrence in wetlands.* Do any of the species listed on DATA FORM 1 have observed morphological or known physiological adaptations (Appendix C, Section 3) for occurrence in wetlands? If so, record species having such adaptations on DATA FORM 1. When two or more dominant species have observed morphological adaptations or known physiological adaptations for occurrence in wetlands, hydrophytic vegetation is present. If so, complete the vegetation portion of DATA FORM 1 and PROCEED TO STEP 14. If not, consider other indicators of hydrophytic vegetation.

c. *Other indicators of hydrophytic vegetation.* Consider other indicators (see Part III, paragraph 35) that the species listed on DATA FORM 1 are commonly found in wetlands. If so, complete the vegetation portion of DATA FORM 1 by recording sources of supporting information, and PROCEED TO STEP 14. If no indicator of hydrophytic vegetation is present, the area at the observation point is not a wetland. In such cases, it is unnecessary to consider soil and hydrology at that observation point. PROCEED TO STEP 17.

- *STEP 14 - Determine whether hydric soils are present.* Examine DATA FORM 1 and determine whether any indicator of hydric soils is present. If so, complete the soils portion of DATA FORM 1 and PROCEED TO STEP 15. If not, the area at the observation point is not a wetland. PROCEED TO STEP 17.

- *STEP 15 - Determine whether wetland hydrology is present.* Examine DATA FORM 1 and determine whether any indicator of wetland hydrology is present. Complete the hydrology portion of DATA FORM 1 and PROCEED TO STEP 16.

- *STEP 16 - Make wetland determination.* When the area at the observation point presently or normally has wetland indicators of all three parameters, it is a wetland. When the area at the observation point presently or normally lacks wetland indicators of one or more parameters, it is a nonwetland. PROCEED TO STEP 17.

- *STEP 17 - Make wetland determination at second observation point.* Locate the second observation point along the first transect and make a wetland determination by repeating procedures described in STEPS 9 through 16. When the area at the second observation point is the same as the area at the first observation point (i.e., both wetlands or both nonwetlands), PROCEED TO STEP 19. When the areas at the two ob-

servation points are different (i.e., one wetlands, the other nonwetlands), PROCEED TO STEP 18.

- *STEP 18 - Determine the wetland boundary between observation points.* Determine the position of the wetland boundary by applying the following procedure:

    a. Look for a change in vegetation or topography. *NOTE: The changes may sometimes be very subtle.* If a change is noted, establish an observation point and repeat STEPS 9 through 16. Complete a DATA FORM 1. If the area at this point is a wetland, proceed toward the nonwetland observation point until a more obvious change in vegetation or topography is noted and repeat the procedure. If there is no obvious change, establish the next observation point approximately halfway between the last observation point and the nonwetland observation point and repeat STEPS 9 through 16.

    b. Make as many additional wetland determinations as necessary to find the wetland boundary. *NOTE: The completed DATA FORM 1's for the original two observation points often will provide a clue as to the parameters that change between the two points.*

    c. When the wetland boundary is found, mark the boundary location on the base map and indicate on the DATA FORM 1 that this represents a wetland boundary. Record the distance of the boundary from one of the two regular observation points. Since the regular observation points represent known distances from the baseline, it will be possible to accurately pinpoint the boundary location on the base map. PROCEED TO STEP 19.

- *STEP 19 - Make wetland determinations at all other required observation points along all transects.* Continue to locate and sample all required observation points along all transects. *NOTE: The procedure described in STEP 18 must be applied at every position where a wetland boundary occurs between successive observation points.* Complete a DATA FORM 1 for each observation point and PROCEED TO STEP 20.

- *STEP 20 - Synthesize data to determine the portion of the area containing wetlands.* Examine all completed copies of DATA FORM 1 (STEP 19), and mark on a copy of the base map the locations of all observation points that are wetlands with a W and all observation points that are nonwetlands with an N. Also, mark all wetland boundaries occurring along transects with an X. If all the observation points are wetlands, the entire area is wetlands. If all observation points are nonwetlands, none of the area is wetlands. If some wetlands and some nonwetlands are present, connect the wetland boundaries (X) by following contour lines between transects. *CAUTION: If the determination is considered to be*

highly controversial, it may be necessary to be more precise in determining the wetland boundary between transects. This is also true for very large areas where the distance between transects is greater. If this is necessary, PROCEED TO STEP 21.

- *STEP 21 - Determine wetland boundary between transects.* Two procedures may be used to determine the wetland boundary between transects, both of which involve surveying:

    a. *Survey contour from wetland boundary along transects.* The first method involves surveying the elevation of the wetland boundaries along transects and then extending the survey to determine the same contour between transects. This procedure will be adequate in areas where there is no significant elevational change between transects. However, if a significant elevational change occurs between transects, either the surveyor must adjust elevational readings to accommodate such changes or the second method must be used. *NOTE: The surveyed wetland boundary must be examined to ensure that no anomalies exist. If these occur, additional wetland determinations will be required in the portion of the area where the anomalies occur, and the wetland boundary must be adjusted accordingly.*

    b. *Additional wetland determinations between transects.* This procedure consists of traversing the area between transects and making additional wetland determinations to locate the wetland boundary at sufficiently close intervals (not necessarily standard intervals) so that the area can be surveyed. Place surveyor flags at each wetland boundary location. Enlist a surveyor to survey the points between transects. From the resulting survey data, produce a map that separates wetlands from nonwetlands.

Section F. Atypical Situations

71. Methods described in this section should be used only when a determination has already been made in Section D or E that positive indicators of hydrophytic vegetation, hydric soils, and/or wetland hydrology could not be found due to effects of recent human activities or natural events. This section is applicable to delineations made in the following types of situations:

a. *Unauthorized activities.* Unauthorized discharges requiring enforcement actions may result in removal or covering of indicators of one or more wetland parameters. Examples include, but are not limited to: (1) alteration or removal of vegetation; (2) placement of dredged or fill material over hydric soils; and/or (3) construction of levees, drainage systems, or

dams that significantly alter the area hydrology. NOTE: This section should not be used for activities that have been previously authorized or those that are exempted from CE regulation. For example, this section is not applicable to areas that have been drained under CE authorization or that did not require CE authorization. Some of these areas may still be wetlands, but procedures described in Section D or E must be used in these cases.

b. *Natural events.* Naturally occurring events may result in either creation or alteration of wetlands. For example, recent beaver dams may impound water, thereby resulting in a shift of hydrology and vegetation to wetlands. However, hydric soil indicators may not have developed due to insufficient time having passed to allow their development. Fire, avalanches, volcanic activity, and changing river courses are other examples. *NOTE: It is necessary to determine whether alterations to an area have resulted in changes that are now the "normal circumstances.*" The relative permanence of the change and whether the area is now functioning as a wetland must be considered.

c. *Man-induced wetlands.* Procedures described in Subsection 4 are for use in delineating wetlands that have been purposely or incidentally created by human activities, but in which wetland indicators of one or more parameters are absent. For example, road construction may have resulted in impoundment of water in an area that previously was nonwetland, thereby effecting hydrophytic vegetation and wetland hydrology in the area. However, the area may lack hydric soil indicators. *NOTE: Subsection D is not intended to bring into CE jurisdiction those manmade wetlands that are exempted under CE regulations or policy.* It is also important to consider whether the man-induced changes are now the "normal circumstances" for the area. Both the relative permanence of the change and the functioning of the area as a wetland are implied.

72. When any of the three types of situations described in paragraph 71 occurs, application of methods described in Sections D and/or E will lead to the conclusion that the area is not a wetland because positive wetland indicators for at least one of the three parameters will be absent. Therefore, apply procedures described in one of the following subsections (as appropriate) to determine whether positive indicators of hydrophytic vegetation, hydric soils, and/or wetland hydrology existed prior to alteration of the area. Once these procedures have been employed, RETURN TO Section D or E to make a wetland determination. PROCEED TO the appropriate subsection.

Subsection 1 - Vegetation

73. Employ the following steps to determine whether hydrophytic vegetation previously occurred:

- *STEP 1 - Describe the type of alteration.* Examine the area and describe the type of alteration that occurred. Look for evidence of selective harvesting, clear cutting, bulldozing, recent conversion to agriculture, or other activities (e.g., burning, discing, or presence of buildings, dams, levees, roads, parking lots, etc.). Determine the approximate date[1] when the alteration occurred. Record observations on DATA FORM 3, and PROCEED TO STEP 2.

- *STEP 2 - Describe effects on vegetation.* Record on DATA FORM 3 a general description of how the activities (STEP 1) have affected the plant communities. Consider the following:

    a. Has all or a portion of the area been cleared of vegetation?

    b. Has only one layer of the plant community (e.g., trees) been removed?

    c. Has selective harvesting resulted in removal of some species?

    d. Has all vegetation been covered by fill, dredged material, or structures?

    e. Have increased water levels resulted in the death of some individuals?

    PROCEED TO STEP 3.

- *STEP 3 - Determine the type of vegetation that previously occurred.* Obtain all possible evidence of the type of plant communities that occurred in the area prior to alteration. Potential sources of such evidence include:

    a. *Aerial photography*. Recent (within 5 years) aerial photography can often be used to document the type of previous vegetation. The general type of plant communities formerly present can usually be determined, and species identification is sometimes possible.

    b. *Onsite inspection.* Many types of activities result in only partial removal of the previous plant communities, and remaining species may be indicative of hydrophytic vegetation. In other cases, plant fragments (e.g., stumps, roots) may be used to reconstruct the plant community types that occurred prior to site alteration. Sometimes, this can be determined by examining piles of debris resulting from land-clearing opera-

[1] It is especially important to determine whether the alteration occurred prior to implementation of Section 404.

tions or excavation to uncover identifiable remains of the previous plant community.

c. *Previous site inspections.* Documented evidence from previous inspections of the area may describe the previous plant communities, particularly in cases where the area was altered after a permit application was denied.

d. *Adjacent vegetation.* Circumstantial evidence of the type of plant communities that previously occurred may sometimes be obtained by examining the vegetation in adjacent areas. If adjacent areas have the same topographic position, soils, and hydrology as the altered area, the plant community types on the altered area were probably similar to those of the adjacent areas.

e. *SCS records.* Most SCS soil surveys include a description of the plant community types associated with each soil type. If the soil type on the altered area can be determined, it may be possible to generally determine the type of plant communities that previously occurred.

f. *Permit applicant.* In some cases, the permit applicant may provide important information about the type of plant communities that occurred prior to alteration.

g. *Public.* Individuals familiar with the area may provide a good general description of the previously occurring plant communities.

h. *NWI wetland maps.* The NWI has developed wetland type maps for many areas. These may be useful in determining the type of plant communities that occurred prior to alteration.

To develop the strongest possible record, all of the above sources should be considered. If the plant community types that occurred prior to alteration can be determined, record them on DATA FORM 3 and also record the basis used for the determination. PROCEED TO STEP 4. If it is impossible to determine the plant community types that occurred on the area prior to alteration, a determination cannot be made using all three parameters. In such cases, the determination must be based on the other two parameters. PROCEED TO Subsection 2 or 3 if one of the other parameters has been altered, or return to the appropriate Subsection of Section D or to Section E, as appropriate.

- *STEP 4 - Determine whether plant community types constitute hydrophytic vegetation.* Develop a list of species that previously occurred on the site (DATA FORM 3). Subject the species list to applicable indicators of hydrophytic vegetation (Part III, paragraph 35). If none of the

indicators are met, the plant communities that previously occurred did not constitute hydrophytic vegetation. If hydrophytic vegetation was present and no other parameter was in question, record appropriate data on the vegetation portion of DATA FORM 3, and return to either the appropriate subsection of Section D or to Section E. If either of the other parameters was also in question, PROCEED TO Subsection 2 or 3.

Subsection 2 - Soils

74. Employ the following steps to determine whether hydric soils previously occurred:

- *STEP 1 - Describe the type of alteration.* Examine the area and describe the type of alteration that occurred. Look for evidence of:

    a. *Deposition of dredged or fill material or natural sedimentation.* In many cases the presence of fill material will be obvious. If so, it will be necessary to dig a hole to reach the original soil (sometimes several feet deep). Fill material will usually be a different color or texture than the original soil (except when fill material has been obtained from like areas onsite). Look for decomposing vegetation between soil layers and the presence of buried organic or hydric soil layers. In accreting or recently formed sandbars in riverine situations, the soils may support hydrophytic vegetation but lack hydric soil characteristics.

    b. *Presence of nonwoody debris at the surface.* This can only be applied in areas where the original soils do not contain rocks. Nonwoody debris includes items such as rocks, bricks, and concrete fragments.

    c. *Subsurface plowing.* Has the area recently been plowed below the A-horizon or to depths of greater than 10 in.?

    d. *Removal of surface layers.* Has the surface soil layer been removed by scraping or natural landslides? Look for bare soil surfaces with exposed plant roots or scrape scars on the surface.

    e. *Presence of man-made structures.* Are buildings, dams, levees, roads, or parking lots present?

Determine the approximate date[1] when the alteration occurred. This may require checking aerial photography, examining building permits, etc. Record on DATA FORM 3, and PROCEED TO STEP 2.

- *STEP 2 - Describe effects on soils.* Record on DATA FORM 3 a general description of how identified activities in STEP 1 have affected the soils. Consider the following:

    a. Has the soil been buried? If so, record the depth of fill and determine whether the original soil is intact.

    b. Has the soil been mixed at a depth below the A-horizon or 10 inches? If so, it will be necessary to examine soil at a depth immediately below the plowed zone. Record supporting evidence.

    c. Has the soil been sufficiently altered to change the soil phase? Describe these changes.

    PROCEED TO STEP 3.

- *STEP 3 - Characterize soils that previously occurred.* Obtain all possible evidence that may be used to characterize soils that previously occurred on the area. Consider the following potential sources of information:

    a. Soil surveys. In many cases, recent soil surveys will be available. If so, determine the soil series that were mapped for the area, and compare these soil series with the list of hydric soils ~~(Appendix D, Section 2)~~. If all soil series are listed as hydric soils, the entire area had hydric soils prior to alteration.

    b. Characterization of buried soils. When fill material has been placed over the original soil without physically disturbing the soil, examine and characterize the buried soils. To accomplish this, dig a hole through the fill material until the original soil is encountered. Determine the point at which the original soil material begins. Remove 12 inches of the original soil from the hole and look for indicators of hydric soils (Part III, paragraphs 44 and/or 45) immediately below the A-horizon or 10 inches (whichever is shallower). Record on DATA FORM 3 the color of the soil matrix, presence of an organic layer, presence of mottles or gleying, and/or presence of iron and manganese concretions. If the original soil is mottled and the

[1] It is especially important to determine whether the alteration occurred prior to implementation of Section 404.

chroma of the soil matrix is 2 or less,[1] a hydric soil was formerly present on the site. If any of these indicators are found, the original soil was a hydric soil. *(NOTE: When the fill material is a thick layer, it might be necessary to use a backhoe or posthole digger to excavate the soil pit.)* If USGS quadrangle maps indicate distinct variation in area topography, this procedure must be applied in each portion of the area that originally had a different surface elevation. Record findings on DATA FORM 3.

c. *Characterization of plowed soils.* Determine the depth to which the soil has been disturbed by plowing. Look for hydric soil characteristics (Part III, paragraphs 44 and/or 45) immediately below this depth. Record findings on DATA FORM 3.

d. *Removal of surface layers.* Dig a hole (Appendix D, Section 1) and determine whether the entire surface layer (A-horizon) has been removed. If so, examine the soil immediately below the top of the subsurface layer (B-horizon) for hydric soil characteristics. As an alternative, examine an undisturbed soil of the same soil series occurring in the same topographic position in an immediately adjacent area that has not been altered. Look for hydric soil indicators immediately below the A-horizon or 10 inches (whichever is shallower), and record findings on DATA FORM 3.

If sufficient data on soils that existed prior to alteration can be obtained to determine whether a hydric soil was present, PROCEED TO STEP 4. If not, a determination cannot be made using soils. Use the other parameters (Subsections 1 and 3) for the determination.

- *STEP 4 - Determine whether hydric soils were formerly present.* Examine the available data and determine whether indicators of hydric soils (Part III, paragraphs 44 and/or 45) were formerly present. If no indicators of hydric soils were found, the original soils were not hydric soils. If indicators of hydric soils were found, record the appropriate indicators on DATA FORM 3 and PROCEED TO Subsection 3 if the hydrology of the area has been significantly altered or return either to the appropriate subsection of Section D or to Section E and characterize the area hydrology.

[1] The matrix chroma must be 1 or less if no mottles are present. The soil must be moist when colors are determined.

Subsection 3 - Hydrology

75. Apply the following steps to determine whether wetland hydrology previously occurred:

- *STEP 1 - Describe the type of alteration.* Examine the area and describe the type of alteration that occurred. Look for evidence of:

    a. *Dams.* Has recent construction of a dam or some natural event (e.g., beaver activity or landslide) caused the area to become increasingly wetter or drier? *NOTE: This activity could have occurred a considerable distance away from the site in question.*

    b. *Levees, dikes, and similar structures.* Have levees or dikes recently been constructed that prevent the area from becoming periodically inundated by overbank flooding?

    c. *Ditching.* Have ditches been constructed recently that cause the area to drain more rapidly following inundation?

    d. *Filling of channels or depressions (land-leveling).* Have natural channels or depressions been recently filled?

    e. *Diversion of water.* Has an upstream drainage pattern been altered that results in water being diverted from the area?

    f. *Ground-water extraction.* Has prolonged and intensive pumping of ground water for irrigation or other purposes significantly lowered the water table and/or altered drainage patterns?

    g. *Channelization.* Have feeder streams recently been channelized sufficiently to alter the frequency and/or duration of inundation?

    Determine the approximate date[1] when the alteration occurred. Record observations on DATA FORM 3 and PROCEED TO STEP 2.

- *STEP 2 - Describe effects of alteration on area hydrology.* Record on DATA FORM 3 a general description of how the observed alteration (STEP 1) has affected the area. Consider the following:

    a. Is the area more frequently or less frequently inundated than prior to alteration? To what degree and why?

[1] It is especially important to determine whether the alteration occurred prior to implementation of Section 404.

b. Is the duration of inundation and soil saturation different than prior to alteration? How much different and why?

PROCEED TO STEP 3.

- *STEP 3 - Characterize the hydrology that previously existed in the area.* Obtain all possible evidence that may be used to characterize the hydrology that previously occurred. Potential sources of information include:

  a. *Stream or tidal gage data.* If a stream or tidal gaging station is located near the area, it may be possible to calculate elevations representing the upper limit of wetlands hydrology based on duration of inundation. Consult hydrologists from the local CE District Office for assistance. The resulting mean sea level elevation will represent the upper limit of inundation for the area in the absence of any alteration. If fill material has not been placed on the area, survey this elevation from the nearest USGS benchmark. Record elevations representing zone boundaries on DATA FORM 3. If fill material has been placed on the area, compare the calculated elevation with elevations shown on a USGS quadrangle or any other survey map that predated site alteration.

  b. *Field hydrologic indicators.* Certain field indicators of wetland hydrology (Part III, paragraph 49) may still be present. Look for watermarks on trees or other structures, drift lines, and debris deposits. Record these on DATA FORM 3. If adjacent undisturbed areas are in the same topographic position and are similarly influenced by the same sources of inundation, look for wetland indicators in these areas.

  c. *Aerial photography.* Examine any available aerial photography and determine whether the area was inundated at the time of the photographic mission. Consider the time of the year that the aerial photography was taken and use only photography taken during the growing season and prior to site alteration.

  d. *Historical records.* Examine any available historical records for evidence that the area has been periodically inundated. Obtain copies of any such information and record findings on DATA FORM 3.

  e. *Floodplain management maps.* Determine the previous frequency of inundation of the area from Floodplain Management Maps (if available). Record flood frequency on DATA FORM 3.

f. *Public or local government officials.* Contact individuals who might have knowledge that the area was periodically inundated.

If sufficient data on hydrology that existed prior to site alteration can be obtained to determine whether wetland hydrology was previously present, PROCEED TO STEP 4. If not, a determination involving hydrology cannot be made. Use other parameters (Subsections 1 and 2) for the wetland determination. Return to either the appropriate subsection of Section D or to Section E and complete the necessary data forms. PROCEED TO STEP 4 if the previous hydrology can be characterized.

- *STEP 4 - Determine whether wetland hydrology previously occurred.* Examine the available data and determine whether indicators of wetland hydrology (Part III, paragraph 49) were present prior to site alteration. If no indicators of wetland hydrology were found, the original hydrology of the area was not wetland hydrology. If indicators of wetland hydrology were found, record the appropriate indicators on DATA FORM 3 and return either to the appropriate subsection of Section D or to Section E and complete the wetland determination.

Subsection 4 - Man-Induced Wetlands

76. A man-induced wetland is an area that has developed at least some characteristics of naturally occurring wetlands due to either intentional or incidental human activities. Examples of man-induced wetlands include irrigated wetlands, wetlands resulting from impoundment (e.g., reservoir shorelines), wetlands resulting from filling of formerly deepwater habitats, dredged material disposal areas, and wetlands resulting from stream channel realignment. Some man-induced wetlands may be subject to Section 404. In virtually all cases, man-induced wetlands involve a significant change in the hydrologic regime, which may either increase or decrease the wetness of the area. Although wetland indicators of all three parameters (i.e., vegetation, soils, and hydrology) may be found in some man-induced wetlands, indicators of hydric soils are usually absent. Hydric soils require long periods (hundreds of years) for development of wetness characteristics, and most man-induced wetlands have not been in existence for a sufficient period to allow development of hydric soil characteristics. Therefore, application of the multiparameter approach in making wetland determinations in man-induced wetlands must be based on the presence of hydrophytic vegetation and wetland hydrology. [1] There must also be documented evidence that the wetland resulted from human activities. Employ the following steps to determine whether an area consists of wetlands resulting from human activities:

[1] Uplands that support hydrophytic vegetation due to agricultural irrigation and that have an obvious hydrologic connection to other "waters of the United States" should not be delineated as wetlands under this subsection.

- *STEP 1 - Determine whether the area represents a potential man-induced wetland.* Consider the following questions:

    a. Has a recent man-induced change in hydrology occurred that caused the area to become significantly wetter?

    b. Has a major man-induced change in hydrology that occurred in the past caused a former deepwater aquatic habitat to become significantly drier?

    c. Has man-induced stream channel realignment significantly altered the area hydrology?

    d. Has the area been subjected to long-term irrigation practices?

    If the answer to any of the above questions is YES, document the approximate time during which the change in hydrology occurred, and PROCEED TO STEP 2. If the answer to all of the questions is NO, procedures described in Section D or E must be used.

- *STEP 2 - Determine whether a permit will be needed if the area is found to be a wetland.* Consider the current CE regulations and policy regarding man-induced wetlands. If the type of activity resulting in the area being a potential man-induced wetland is exempted by regulation or policy, no further action is needed. If not exempt, PROCEED TO STEP 3.

- *STEP 3 - Characterize the area vegetation, soils, and hydrology.* Apply procedures described in Section D (routine determinations) or Section E (comprehensive determinations) to the area. Complete the appropriate data forms and PROCEED TO STEP 4.

- *STEP 4 - Wetland determination.* Based on information resulting from STEP 3, determine whether the area is a wetland. When wetland indicators of all three parameters are found, the area is a wetland. When indicators of hydrophytic vegetation and wetland hydrology are found *and* there is documented evidence that the change in hydrology occurred so recently that soils could not have developed hydric characteristics, the area is a wetland. In such cases, it is assumed that the soils are functioning as hydric soils. *CAUTION: If hydrophytic vegetation is being maintained only because of man-induced wetland hydrology that would no longer exist if the activity (e.g., irrigation) were to be terminated, the area should not be considered a wetland.*

Section G - Problem Areas

77. There are certain wetland types and/or conditions that may make application of indicators of one or more parameters difficult, at least at certain times of the year. These are not considered to be atypical situations. Instead, they are wetland types in which wetland indicators of one or more parameters may be periodically lacking due to *normal* seasonal or annual variations in environmental conditions that result from causes other than human activities or catastrophic natural events.

Types of problem areas

78. Representative examples of potential problem areas, types of variations that occur, and their effects on wetland indicators are presented in the following subparagraphs. Similar situations may sometimes occur in other wetland types. *NOTE: This section is not intended to bring nonwetland areas having wetland indicators of two, but not all three, parameters into Section 404 jurisdiction.*

a. *Wetlands on drumlins.* Slope wetlands occur in glaciated areas in which thin soils cover relatively impermeable glacial till or in which layers of glacial till have different hydraulic conditions that produce a broad zone of ground-water seepage. Such areas are seldom, if ever, flooded, but downslope groundwater movement keeps the soils saturated for a sufficient portion of the growing season to produce anaerobic and reducing soil conditions. This fosters development of hydric soil characteristics and selects for hydrophytic vegetation. Indicators of wetland hydrology may be lacking during the drier portion of the growing season.

b. *Seasonal wetlands.* In many regions (especially in western states), depressional areas occur that have wetland indicators of all three parameters during the wetter portion of the growing season, but normally lack wetland indicators of hydrology and/or vegetation during the drier portion of the growing season. Obligate hydrophytes and facultative wetland plant species ~~(Appendix C, Section 1 or 2)~~ normally are dominant during the wetter portion of the growing season, while upland species (annuals) may be dominant during the drier portion of the growing season. These areas may be inundated during the wetter portion of the growing season, but wetland hydrology indicators may be totally lacking during the drier portion of the growing season. It is important to establish that an area truly is a water body. Water in a depression normally must be sufficiently persistent to exhibit an ordinary high-water mark or the presence of wetland characteristics before it can be considered as a water body potentially subject to Clean Water Act jurisdiction. The determination that an area exhibits wetland characteristics for a sufficient portion of the growing season to qualify as a wetland under the Clean Water Act must be made on a case-by-case basis. Such determinations should consider the respective length of time that the area exhibits upland and wetland characteristics, and the manner in which the area fits

into the overall ecological system as a wetland. Evidence concerning the persistence of an area's wetness can be obtained from its history, vegetation, soil, drainage characteristics, uses to which it has been subjected, and weather or hydrologic records.

c. *Prairie potholes.* Prairie potholes normally occur as shallow depressions in glaciated portions of the north-central United States. Many are landlocked, while others have a drainage outlet to streams or other potholes. Most have standing water for much of the growing season in years of normal or above normal precipitation, but are neither inundated nor have saturated soils during most of the growing season in years of below normal precipitation. During dry years, potholes often become incorporated into farming plans, and are either planted to row crops (e.g., soybeans) or are mowed as part of a haying operation. When this occurs, wetland indicators of one or more parameters may be lacking. For example, tillage would eliminate any onsite hydrologic indicator, and would make detection of soil and vegetation indicators much more difficult.

d. *Vegetated flats.* In both coastal and interior areas throughout the Nation, vegetated flats are often dominated by annual species that are categorized as OBL. Application of procedures described in Sections D and E during the growing season will clearly result in a positive wetland determination. However, these areas will appear to be unvegetated mudflats when examined during the nongrowing season, and the area would not qualify at that time as a wetland due to an apparent lack of vegetation.

Wetland determinations in problem areas

79. Procedures for making wetland determinations in problem areas are presented below. Application of these procedures is appropriate only when a decision has been made in Section D or E that wetland indicators of one or more parameters were lacking, probably due to normal seasonal or annual variations in environmental conditions. Specific procedures to be used will vary according to the nature of the area, site conditions, and parameter(s) affected by the variations in environmental conditions. A determination must be based on the best evidence available to the field inspector, including:

a. Available information (Section B).

b. Field data resulting from an onsite inspection.

c. Basic knowledge of the ecology of the particular community type(s) and environmental conditions associated with the community type.

NOTE: The procedures described below should only be applied to parameters not adequately characterized in Section D or E. Complete the following steps:

- *STEP 1 - Identify the parameter(s) to be considered.* Examine the DATA FORM 1 (Section D or E) and identify the parameter(s) that must be given additional consideration. PROCEED TO STEP 2.

- *STEP 2 - Determine the reason for further consideration.* Determine the reason why the parameter(s) identified in STEP 1 should be given further consideration. This will require a consideration and documentation of:

    a. Environmental condition(s) that have impacted the parameter(s).

    b. Impacts of the identified environmental condition(s) on the parameter(s) in question.

  Record findings in the comments section of DATA FORM 1. PROCEED TO STEP 3.

- *STEP 3 - Document available information for parameter(s) in question.* Examine the available information and consider personal ecological knowledge of the range of normal environmental conditions of the area. Local experts (e.g., university personnel) may provide additional information. Record information on DATA FORM 1. PROCEED TO STEP 4.

- *STEP 4 - Determine whether wetland indicators are normally present during a portion of the growing season.* Examine the information resulting from STEP 3 and determine whether wetland indicators are *normally* present during part of the growing season. If so, record on DATA FORM 1 the indicators normally present and return to Section D or Section E and make a wetland determination. If no information can be found that wetland indicators of all three parameters are normally present during part of the growing season, the determination must be made using procedures described in Section D or Section E.

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Appendix A
Glossary

Active water table. A condition in which the zone of soil saturation fluctuates, resulting in periodic anaerobic soil conditions. Soils with an active water table often contain bright mottles and matrix chromas of 2 or less.

Adaptation. A modification of a species that makes it more fit for existence under the conditions of its environment. These modifications are the result of genetic selection processes.

Adventitious roots. Roots found on plant stems in positions where they normally do not occur.

Aerenchymous tissue. A type of plant tissue in which cells are unusually large and arranged in a manner that results in air spaces in the plant organ. Such tissues are often referred to as spongy and usually provide increased buoyancy.

Aerobic. A situation in which molecular oxygen is a part of the environment.

Anaerobic. A situation in which molecular oxygen is absent (or effectively so) from the environment.

Aquatic roots. Roots that develop on stems above the normal position occupied by roots in response to prolonged inundation.

Aquic moisture regime. A mostly reducing soil moisture regime nearly free of dissolved oxygen due to saturation by ground water or its capillary fringe and occurring at periods when the soil temperature at 19.7 in. is greater than 5 °C.

Arched roots. Roots produced on plant stems in a position above the normal position of roots, which serve to brace the plant during and following periods of prolonged inundation.

Areal cover. A measure of dominance that defines the degree to which above-ground portions of plants (not limited to those rooted in a sample plot) cover the ground surface. It is possible for the total areal cover in a community to exceed 100 percent because (a) most plant communities consist of two or more vegetative strata; (b) areal cover is estimated by vegetative layer; and (c) foliage within a single layer may overlap.

Atypical situation. As used herein, this term refers to areas in which one or more parameters (vegetation, soil, and/or hydrology) have been sufficiently altered by recent human activities or natural events to preclude the presence of wetland indicators of the parameter.

Backwater flooding. Situations in which the source of inundation is overbank flooding from a nearby stream.

Basal area. The cross-sectional area of a tree trunk measured in square inches, square centimeters, etc. Basal area is normally measured at 4.5 ft above the ground level and is used as a measure of dominance. The most easily used tool for measuring basal area is a tape marked in square inches. When plot-less methods are used, an angle gauge or prism will provide a means for rapidly determining basal area. This term is also applicable to the cross-sectional area of a clumped herbaceous plant, measured at 1.0 in. above the soil surface.

Bench mark. A fixed, more or less permanent reference point or object, the elevation of which is known. The U.S. Geological Survey (USGS) installs brass caps in bridge abutments or otherwise permanently sets bench marks at convenient locations nationwide. The elevations on these marks are referenced to the National Geodetic Vertical Datum (NGVD), also commonly known as mean sea level (MSL). Locations of these bench marks on USGS quadrangle maps are shown as small triangles. However, the marks are sometimes destroyed by construction or vandalism. The existence of any bench mark should be field verified before planning work that relies on a particular reference point. The USGS and/or local state surveyor's office can provide information on the existence, exact location, and exact elevation of bench marks.

Biennial. An event that occurs at 2-year intervals.

Buried soil. A once-exposed soil now covered by an alluvial, loessal, or other deposit (including man-made).

Canopy layer. The uppermost layer of vegetation in a plant community. In forested areas, mature trees comprise the canopy layer, while the tallest herbaceous species constitute the canopy layer in a marsh.

Capillary fringe. A zone immediately above the water table (zero gauge pressure) in which water is drawn upward from the water table by capillary action.

Chemical reduction. Any process by which one compound or ion acts as an electron donor. In such cases, the valence state of the electron donor is decreased.

Chroma. The relative purity or saturation of a color; intensity of distinctive hue as related to grayness; one of the three variables of color.

Comprehensive wetland determination. A type of wetland determination that is based on the strongest possible evidence, requiring the collection of quantitative data.

Concretion. A local concentration of chemical compounds (e.g., calcium carbonate, iron oxide) in the form of a grain or nodule of varying size, shape, hardness, and color. Concretions of significance in hydric soils are usually iron and/or manganese oxides occurring at or near the soil surface, which develop under conditions of prolonged soil saturation.

Contour. An imaginary line of constant elevation on the ground surface. The corresponding line on a map is called a "contour line."

Criteria. Standards, rules, or tests on which a judgment or decision may be based.

Deepwater aquatic habitat. Any open water area that has a mean annual water depth >6.6 ft, lacks soil, and/or is either unvegetated or supports only floating or submersed macrophytes.

Density. The number of individuals of a species per unit area.

Detritus. Minute fragments of plant parts found on the soil surface. When fused together by algae or soil particles, this is an indicator that surface water was recently present.

Diameter at breast height (DBH). The width of a plant stem as measured at 4.5 ft above the ground surface.

Dike. A bank (usually earthen) constructed to control or confine water.

Dominance. As used herein, a descriptor of vegetation that is related to the standing crop of a species in an area, usually measured by height, areal cover, or basal area (for trees).

Dominant species. As used herein, a plant species that exerts a controlling influence on or defines the character of a community.

Drained. A condition in which ground or surface water has been reduced or eliminated from an area by artificial means.

Drift line. An accumulation of debris along a contour (parallel to the water flow) that represents the height of an inundation event.

Duration (inundation/soil saturation). The length of time during which water stands at or above the soil surface (inundation), or during which the soil is saturated. As used herein, duration refers to a period during the growing season.

Ecological tolerance. The range of environmental conditions in which a plant species can grow.

Emergent plant. A rooted herbaceous plant species that has parts extending above a water surface.

Field capacity. The percentage of water remaining in a soil after it has been saturated and after free drainage is negligible.

Fill material. Any material placed in an area to increase surface elevation.

Flooded. A condition in which the soil surface is temporarily covered with flowing water from any source, such as streams overflowing their banks, runoff from adjacent or surrounding slopes, inflow from high tides, or any combination of sources.

Flora. A list of all plant species that occur in an area.

Frequency (inundation or soil saturation). The periodicity of coverage of an area by surface water or soil saturation. It is usually expressed as the number of years (e.g., 50 years) the soil is inundated or saturated at least once each year during part of the growing season per 100 years or as a l-, 2-, 5-year, etc., inundation frequency.

Frequency (vegetation). The distribution of individuals of a species in an area. It is quantitatively expressed as

$$\frac{\text{Number of samples containing species A}}{\text{Total number of samples}} \times 100$$

More than one species may have a frequency of 100 percent within the same area.

Frequently flooded. A flooding class in which flooding is likely to occur often under normal weather conditions (more than 50-percent chance of flooding in any year or more than 50 times in 100 years).

Gleyed. A soil condition resulting from prolonged soil saturation, which is manifested by the presence of bluish or greenish colors through the soil mass or in mottles (spots or streaks) among other colors. Gleying occurs under re-

ducing soil conditions resulting from soil saturation, by which iron is reduced predominantly to the ferrous state.

Ground water. That portion of the water below the ground surface that is under greater pressure than atmospheric pressure.

Growing season. The portion of the year when soil temperatures at 19.7 in. below the soil surface are higher than biologic zero (5 °C) (U.S. Department of Agriculture—Soil Conservation Service 1985). For ease of determination this period can be approximated by the number of frost-free days (U.S Department of the Interior 1970).

Habitat. The environment occupied by individuals of a particular species, population, or community.

Headwater flooding. A situation in which an area becomes inundated directly by surface runoff from upland areas.

Herb. A nonwoody individual of a macrophytic species. In this manual, seedlings of woody plants (including vines) that are less than 3.2 ft in height are considered to be herbs.

Herbaceous layer. Any vegetative stratum of a plant community that is composed predominantly of herbs.

Histic epipedon. An 8- to 16-in. soil layer at or near the surface that is saturated for 30 consecutive days or more during the growing season in most years and contains a minimum of 20 percent organic matter when no clay is present or a minimum of 30 percent organic matter when 60 percent or greater clay is present.

Histosols. An order in soil taxonomy composed of organic soils that have organic soil materials in more than half of the upper 80 cm or that are of any thickness if directly overlying bedrock.

Homogeneous vegetation. A situation in which the same plant species association occurs throughout an area.

Hue. A characteristic of color that denotes a color in relation to red, yellow, blue, etc; one of the three variables of color. Each color chart in the Munsell Color Book (Munsell Color 1975) consists of a specific hue.

Hydric soil. A soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation (U.S. Department of Agriculture—Soil Conservation Service 1985). Hydric soils that occur in areas having positive indicators of hydrophytic vegetation and wetland hydrology are wetland soils.

Hydric soil condition. A situation in which characteristics exist that are associated with soil development under reducing conditions.

Hydrologic regime. The sum total of water that occurs in an area on average during a given period.

Hydrologic zone. An area that is inundated or has saturated soils within a specified range of frequency and duration of inundation and soil saturation.

Hydrology. The science dealing with the properties, distribution, and circulation of water.

Hydrophyte. Any macrophyte that grows in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content; plants typically found in wet habitats.

Hydrophytic vegetation. The sum total of macrophytic plant life growing in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content. When hydrophytic vegetation comprises a community where indicators of hydric soils and wetland hydrology also occur, the area has wetland vegetation.

Hypertrophied lenticels. An exaggerated (oversized) pore on the surface of stems of woody plants through which gases are exchanged between the plant and the atmosphere. The enlarged lenticels serve as a mechanism for increasing oxygen to plant roots during periods of inundation and/or saturated soils.

Importance value. A quantitative term describing the relative influence of a plant species in a plant community, obtained by summing any combination of relative frequency, relative density, and relative dominance.

Indicator. As used in this manual, an event, entity, or condition that typically characterizes a prescribed environment or situation; indicators determine or aid in determining whether or not certain stated circumstances exist.

Indicator status. One of the categories (e.g., OBL) that describes the estimated probability of a plant species occurring in wetlands.

Intercellular air space. A cavity between cells in plant tissues, resulting from variations in cell shape and configuration. Aerenchymous tissue (a morphological adaptation found in many hydrophytes) often has large intercellular air spaces.

Inundation. A condition in which water from any source temporarily or permanently covers a land surface.

Levee. A natural or man-made feature of the landscape that restricts movement of water into or through an area.

Liana. As used in this manual, a layer of vegetation in forested plant communities that consists of woody vines. The term may also be applied to a given species.

Limit of biological activity. With reference to soils, the zone below which conditions preclude normal growth of soil organisms. This term often is used to refer to the temperature (5 °C) in a soil below which metabolic processes of soil microorganisms, plant roots, and animals are negligible.

Long duration (flooding). A flooding class in which the period of inundation for a single event ranges from 7 days to 1 month.

Macrophyte. Any plant species that can be readily observed without the aid of optical magnification. This includes all vascular plant species and mosses (e.g., *Sphagnum* spp.), as well as large algae (e.g., *Cara* spp., kelp).

Macrophytic. A term referring to a plant species that is a macrophyte.

Major portion of the root zone. The portion of the soil profile in which more than 50 percent of plant roots occur. In wetlands, this usually constitutes the upper 12 in. of the profile.

Man-induced wetland. Any area that develops wetland characteristics due to some activity (e.g., irrigation) of man.

Mapping unit. As used in this manual, some common characteristic of soil, vegetation, and/or hydrology that can be shown at the scale of mapping for the defined purpose and objectives of a survey.

Mean sea level. A datum, or "plane of zero elevation," established by averaging all stages of oceanic tides over a 19-year tidal cycle or "epoch." This plane is corrected for curvature of the earth and is the standard reference for elevations on the earth's surface. The correct term for mean sea level is the National Geodetic Vertical Datum (NGVD).

Mesophytic. Any plant species growing where soil moisture and aeration conditions lie between extremes. These species are typically found in habitats with average moisture conditions, neither very dry nor very wet.

Metabolic processes. The complex of internal chemical reactions associated with life-sustaining functions of an organism.

Method. A particular procedure or set of procedures to be followed.

Mineral soil. A soil consisting predominantly of, and having its properties determined predominantly by, mineral matter usually containing less than 20 percent organic matter.

Morphological adaptation. A feature of structure and form that aids in fitting a species to its particular environment (e.g., buttressed base, adventitious roots, aerenchymous tissue).

Mottles. Spots or blotches of different color or shades of color interspersed within the dominant color in a soil layer, usually resulting from the presence of periodic reducing soil conditions.

Muck. Highly decomposed organic material in which the original plant parts are not recognizable.

Multitrunk. A situation in which a single individual of a woody plant species has several stems.

Nonhydric soil. A soil that has developed under predominantly aerobic soil conditions. These soils normally support mesophytic or xerophytic species.

Nonwetland. Any area that has sufficiently dry conditions that indicators of hydrophytic vegetation, hydric soils, and/or wetland hydrology are lacking. As used in this manual, any area that is neither a wetland, a deepwater aquatic habitat, nor other special aquatic site.

Organic pan. A layer usually occurring at 12 to 30 in. below the soil surface in coarse-textured soils, in which organic matter and aluminum (with or without iron) accumulate at the point where the top of the water table most often occurs. Cementing of the organic matter slightly reduces permeability of this layer.

Organic soil. A soil is classified as an organic soil when it is: (1) saturated for prolonged periods (unless artificially drained) and has more than 30 percent organic matter if the mineral fraction is more than 50 percent clay, or more than 20 percent organic matter if the mineral fraction has no clay; or (2) never saturated with water for more than a few days and having more than 34 percent organic matter.

Overbank flooding. Any situation in which inundation occurs as a result of the water level of a stream rising above bank level.

Oxidation-reduction process. A complex of biochemical reactions in soil that influences the valence state of component elements and their ions. Prolonged soil saturation during the growing season elicits anaerobic conditions that shift the overall process to a reducing condition.

Oxygen pathway. The sequence of cells, intercellular spaces, tissues, and organs, through which molecular oxygen is transported in plants. Plant species having pathways for oxygen transport to the root system are often adapted for life in saturated soils.

Parameter. A characteristic component of a unit that can be defined. Vegetation, soil, and hydrology are three parameters that may be used to define wetlands.

Parent material. The unconsolidated and more or less weathered mineral or organic matter from which a soil profile develops.

Ped. A unit of soil structure (e.g., aggregate, crumb, prism, block, or granule) formed by natural processes.

Peraquic moisture regime. A soil condition in which a reducing environment always occurs due to the presence of ground water at or near the soil surface.

Periodically. Used herein to define detectable regular or irregular saturated soil conditions or inundation, resulting from ponding of ground water, precipitation, overland flow, stream flooding, or tidal influences that occur(s) with hours, days, weeks, months, or even years between events.

Permeability. A soil characteristic that enables water or air to move through the profile, measured as the number of inches per hour that water moves downward through the saturated soil. The rate at which water moves through the least permeable layer governs soil permeability.

Physiognomy. A term used to describe a plant community based on the growth habit (e.g., trees, herbs, lianas) of the dominant species.

Physiological adaptation. A feature of the basic physical and chemical activities that occurs in cells and tissues of a species, which results in it being better fitted to its environment (e.g., ability to absorb nutrients under low oxygen tensions).

Plant community. All of the plant populations occurring in a shared habitat or environment.

Plant cover. See areal cover.

Pneumatophore. Modified roots that may function as a respiratory organ in species subjected to frequent inundation or soil saturation (e.g., cypress knees).

Ponded. A condition in which water stands in a closed depression. Water may be removed only by percolation, evaporation, and/or transpiration.

Poorly drained. Soils that commonly are wet at or near the surface during a sufficient part of the year that field crops cannot be grown under natural conditions. Poorly drained conditions are caused by a saturated zone, a layer with low hydraulic conductivity, seepage, or a combination of these conditions.

Population. A group of individuals of the same species that occurs in a given area.

Positive wetland indicator. Any evidence of the presence of hydrophytic vegetation, hydric soil, and/or wetland hydrology in an area.

Prevalent vegetation. The plant community or communities that occur in an area during a given period. The prevalent vegetation is characterized by the dominant macrophytic species that comprise the plant community.

Quantitative. A precise measurement or determination expressed numerically.

Range. As used herein, the geographical area in which a plant species is known to occur.

Redox potential. A measure of the tendency of a system to donate or accept electrons, which is governed by the nature and proportions of the oxidizing and reducing substances contained in the system.

Reducing environment. An environment conducive to the removal of oxygen and chemical reduction of ions in the soils.

Relative density. A quantitative descriptor, expressed as a percent, of the relative number of individuals of a species in an area; it is calculated by

$$\frac{\text{Number of individuals of species A}}{\text{Total number of individuals of all species}} \times 100$$

Relative dominance. A quantitative descriptor, expressed as a percent, of the relative size or cover of individuals of a species in an area; it is calculated by

$$\frac{\text{Amount}^{1} \text{ of species A}}{\text{Total amount of all species}} \times 100$$

Relative frequency. A quantitative descriptor, expressed as a percent, of the relative distribution of individuals of a species in an area; it is calculated by

$$\frac{\text{Frequency of species A}}{\text{Total frequency of all species}} \times 100$$

Relief. The change in elevation of a land surface between two points; collectively, the configuration of the earth's surface, including such features as hills and valleys.

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[1] The "amount" of a species may be based on percent areal cover, basal area, or height.

Reproductive adaptation. A feature of the reproductive mechanism of a species that results in it being better fitted to its environment (e.g., ability for seed germination under water).

Respiration. The sum total of metabolic processes associated with conversion of stored (chemical) energy into kinetic (physical) energy for use by an organism.

Rhizosphere. The zone of soil in which interactions between living plant roots and microorganisms occur.

Root zone. The portion of a soil profile in which plant roots occur.

Routine wetland determination. A type of wetland determination in which office data and/or relatively simple, rapidly applied onsite methods are employed to determine whether or not an area is a wetland. Most wetland determinations are of this type, which usually does not require collection of quantitative data.

Sample plot. An area of land used for measuring or observing existing conditions.

Sapling/shrub. A layer of vegetation composed of woody plants <3.0 in. in diameter at breast height but greater than 3.2 ft in height, exclusive of woody vines.

Saturated soil conditions. A condition in which all easily drained voids (pores) between soil particles in the root zone are temporarily or permanently filled with water to the soil surface at pressures greater than atmospheric.

Soil. Unconsolidated mineral and organic material that supports, or is capable of supporting, plants, and which has recognizable properties due to the integrated effect of climate and living matter acting upon parent material, as conditioned by relief over time.

Soil horizon. A layer of soil or soil material approximately parallel to the land surface and differing from adjacent genetically related layers in physical, chemical, and biological properties or characteristics (e.g., color, structure, texture, etc.).

Soil matrix. The portion of a given soil having the dominant color. In most cases, the matrix will be the portion of the soil having more than 50 percent of the same color.

Soil permeability. The ease with which gases, liquids, or plant roots penetrate or pass through a layer of soil.

Soil phase. A subdivision of a soil series having features (e.g., slope, surface texture, and stoniness) that affect the use and management of the soil, but

which do not vary sufficiently to differentiate it as a separate series. These are usually the basic mapping units on detailed soil maps produced by the Soil Conservation Service.

Soil pore. An area within soil occupied by either air or water, resulting from the arrangement of individual soil particles or peds.

Soil profile. A vertical section of a soil through all its horizons and extending into the parent material.

Soil series. A group of soils having horizons similar in differentiating characteristics and arrangement in the soil profile, except for texture of the surface horizon.

Soil structure. The combination or arrangement of primary soil particles into secondary particles, units, or peds.

Soil surface. The upper limits of the soil profile. For mineral soils, this is the upper limit of the highest (Al) mineral horizon. For organic soils, it is the upper limit of undecomposed, dead organic matter.

Soil texture. The relative proportions of the various sizes of particles in a soil.

Somewhat poorly drained. Soils that are wet near enough to the surface or long enough that planting or harvesting operations or crop growth is markedly restricted unless artificial drainage is provided. Somewhat poorly drained soils commonly have a layer with low hydraulic conductivity, wet conditions high in the profile, additions of water through seepage, or a combination of these conditions.

Stilted roots. Aerial roots arising from stems (e.g., trunk and branches), presumably providing plant support (e.g., *Rhizophora mangle).*

Stooling. A form of asexual reproduction in which new shoots are produced at the base of senescing stems, often resulting in a multitrunk growth habit.

Stratigraphy. Features of geology dealing with the origin, composition, distribution, and succession of geologic strata (layers).

Substrate. The base or substance on which an attached species is growing.

Surface water. Water present above the substrate or soil surface.

Tidal. A situation in which the water level periodically fluctuates due to the action of lunar and solar forces upon the rotating earth.

Topography. The configuration of a surface, including its relief and the position of its natural and man-made features.

Transect. As used herein, a line on the ground along which observations are made at some interval.

Transition zone. The area in which a change from wetlands to nonwetlands occurs. The transition zone may be narrow or broad.

Transpiration. The process in plants by which water vapor is released into the gaseous environment, primarily through stomata.

Tree. A woody plant >3.0 in. in diameter at breast height, regardless of height (exclusive of woody vines).

Typical. That which normally, usually, or commonly occurs.

Typically adapted. A term that refers to a species being normally or commonly suited to a given set of environmental conditions, due to some feature of its morphology, physiology, or reproduction.

Unconsolidated parent material. Material from which a soil develops, usually formed by weathering of rock or placement in an area by natural forces (e.g., water, wind, or gravity).

Under normal circumstances. As used in the definition of wetlands, this term refers to situations in which the vegetation has not been substantially altered by man's activities.

Uniform vegetation. As used herein, a situation in which the same group of dominant species generally occurs throughout a given area.

Upland. As used herein, any area that does not qualify as a wetland because the associated hydrologic regime is not sufficiently wet to elicit development of vegetation, soils, and/or hydrologic characteristics associated with wetlands. Such areas occurring within floodplains are more appropriately termed nonwetlands.

Value (soil color). The relative lightness or intensity of color, approximately a function of the square root of the total amount of light reflected from a surface; one of the three variables of color.

Vegetation. The sum total of macrophytes that occupy a given area.

Vegetation layer. A subunit of a plant community in which all component species exhibit the same growth form (e.g., trees, saplings/shrubs, herbs).

Very long duration (flooding). A duration class in which the length of a single inundation event is greater than 1 month.

Very poorly drained. Soils that are wet to the surface most of the time. These soils are wet enough to prevent the growth of important crops (except rice) unless artificially drained.

Watermark. A line on a tree or other upright structure that represents the maximum static water level reached during an inundation event.

Water table. The upper surface of ground water or that level below which the soil is saturated with water. It is at least 6 in. thick and persists in the soil for more than a few weeks.

Wetlands. Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

Wetland boundary. The point on the ground at which a shift from wetlands to nonwetlands or aquatic habitats occurs. These boundaries usually follow contours.

Wetland determination. The process or procedure by which an area is adjudged a wetland or nonwetland.

Wetland hydrology. The sum total of wetness characteristics in areas that are inundated or have saturated soils for a sufficient duration to support hydrophytic vegetation.

Wetland plant association. Any grouping of plant species that recurs wherever certain wetland conditions occur.

Wetland soil. A soil that has characteristics developed in a reducing atmosphere, which exists when periods of prolonged soil saturation result in anaerobic conditions. Hydric soils that are sufficiently wet to support hydrophytic vegetation are wetland soils.

Wetland vegetation. The sum total of macrophytic plant life that occurs in areas where the frequency and duration of inundation or soil saturation produce permanently or periodically saturated soils of sufficient duration to exert a controlling influence on the plant species present. As used herein, hydrophytic vegetation occurring in areas that also have hydric soils and wetland hydrology may be properly referred to as wetland vegetation.

Woody vine. See liana.

Xerophytic. A plant species that is typically adapted for life in conditions where a lack of water is a limiting factor for growth and/or reproduction. These species are capable of growth in extremely dry conditions as a result of morphological, physiological, and/or reproductive adaptations.

Appendix B
Blank and Example Data Forms

USER NOTES: The following field data form ("Data Form, Routine Wetland Determination, 1987 COE Wetlands Delineation Manual") dated 3/92 is the HQUSACE-approved replacement for Data Form 1 given in the 1987 Manual. (HQUSACE, 6 Mar 92)

DATA FORM
ROUTINE WETLAND DETERMINATION
(1987 COE Wetlands Delineation Manual)

Project/Site: _____ Applicant/Owner: _____ Investigator: _____	Date: _____ County: _____ State: _____
Do Normal Circumstances exist on the site? Yes No Is the site significantly disturbed (Atypical Situation)? Yes No Is the area a potential Problem Area? Yes No (If needed, explain on reverse.)	Community ID: _____ Transect ID: _____ Plot ID: _____

VEGETATION

Dominant Plant Species	Stratum	Indicator	Dominant Plant Species	Stratum	Indicator
1.			9.		
2.			10.		
3.			11.		
4.			12.		
5.			13.		
6.			14.		
7.			15.		
8.			16.		

Percent of Dominant Species that are OBL, FACW or FAC (excluding FAC-). _____

Remarks:

HYDROLOGY

___ Recorded Data (Describe in Remarks):
- ___ Stream, Lake, or Tide Gauge
- ___ Aerial Photographs
- ___ Other

___ No Recorded Data Available

Field Observations:

Depth of Surface Water: _____(in.)

Depth to Free Water in Pit: _____(in.)

Depth to Saturated Soil: _____(in.)

Wetland Hydrology Indicators:

Primary Indicators:
- ___ Inundated
- ___ Saturated in Upper 12 Inches
- ___ Water Marks
- ___ Drift Lines
- ___ Sediment Deposits
- ___ Drainage Patterns in Wetlands

Secondary Indicators (2 or more required):
- ___ Oxidized Root Channels in Upper 12 Inches
- ___ Water-Stained Leaves
- ___ Local Soil Survey Data
- ___ FAC-Neutral Test
- ___ Other (Explain in Remarks)

Remarks:

SOILS

Map Unit Name
(Series and Phase): _____ Drainage Class: _____

Field Observations

Taxonomy (Subgroup): _____ Confirm Mapped Type? Yes No

Profile Description:

Depth (inches)	Horizon	Matrix Color (Munsell Moist)	Mottle Colors (Munsell Moist)	Mottle Abundance/ Size/Contrast	Texture, Concretions, Structure, etc.

Hydric Soil Indicators:

___ Histosol
___ Histic Epipedon
___ Sulfidic Odor
___ Aquic Moisture Regime
___ Reducing Conditions
___ Gleyed or Low-Chroma Colors
___ Concretions
___ High Organic Content in Surface Layer in Sandy Soils
___ Organic Streaking in Sandy Soils
___ Listed on Local Hydric Soils List
___ Listed on National Hydric Soils List
___ Other (Explain in Remarks)

Remarks:

WETLAND DETERMINATION

Hydrophytic Vegetation Present?	Yes	No	(Circle)	
Wetland Hydrology Present?	Yes	No		
Hydric Soils Present?	Yes	No		
				(Circle)
Is this Sampling Point Within a Wetland?				Yes No

Remarks:

Approved by HQUSACE 3/92

DATA FORM 1

WETLAND DETERMINATION

Applicant Name:_____ Application Number:_____ Project Name:_____

State:_____ County:_____ Legal Description: Township:_____ Range:_____

Date:_____ Plot No.:_____ Section:_____

Vegetation [list the three dominant species in each vegetation layer (5 if only 1 or 2 layers)]. Indicate species with observed morphological or known physiological adaptations with an asterisk.

Species	Indicator Status	Species	Indicator Status
Trees		Herbs	
1.		7.	
2.		8.	
3.		9.	
Saplings/shrubs		Woody vines	
4.		10.	
5.		11.	
6.		12.	

% of species that are OBL, FACW, and/or FAC:____. Other indicators:_____.

Hydrophytic vegetation: Yes ____ No ____. Basis:_____.

Soil

Series and phase:_____ On hydric soils list? Yes_____; No____.

Mottled: Yes_____; No_____. Mottle color:_____; Matrix color:_____.

Gleyed: Yes_____ No_____ Other indicators:_____.

Hydric soils: Yes_____ No_____; Basis:_____.

Hydrology

Inundated: Yes_____; No_____. Depth of standing water:_____.

Saturated soils: Yes_____; No_____. Depth to saturated soil:_____.

Other indicators:_____.

Wetland hydrology: Yes_____; No_____. Basis:_____.

Atypical situation: Yes____; No_____.

Normal Circumstances? Yes_____ No_____.

Wetland Determination: Wetland_____; Nonwetland_____.

Comments:

Determined by:_____

DATA FORM 2

VEGETATION-COMPREHENSIVE DETERMINATION

Applicant Name:_____ Application No.:_____ Project Name:_____

Location:_____ Plot #:_____ Date:_____ Determined By:_____

VEGETATION LAYER

TREES	BASAL AREA	TOTAL BASAL AREA	RANK	HERBS	MIDPOINT OF % COVER CLASS	RANK
1				1		
2				2		
3				3		
4				4		
5				5		
6				6		
7				7		
8				8		
9				9		
10				10		

SAPLINGS/SHRUBS	MIDPOINT OF HEIGHT CLASS	TOTAL HEIGHT CLASS	RANK	WOODY VINES	NUMBER OF STEMS	RANK
1				1		
2				2		
3				3		
4				4		
5				5		
6				6		
7				7		
8				8		
9				9		
10				10		

DATA FORM 3

ATYPICAL SITUATIONS

Applicant Name:_____ Application Number:_____ Project Name:_____

Location:_____ Plot Number:_____ Date:_____

A. VEGETATION:

1. Type of Alteration:_____

_____

_____.

2. Effect on Vegetation:_____

_____

_____.

3. Previous Vegetation:_____

(Attach documentation) _____

_____.

4. Hydrophytic Vegetation? Yes_____No_____.

B. SOILS:

1. Type of Alteration:_____

_____

_____.

2. Effect on Soils:_____

_____

_____.

3. Previous Soils:_____

(Attach documentation) _____

_____.

4. Hydric Soils? Yes_____No_____.

C. HYDROLOGY:

1. Type of Alteration:_____

_____

_____.

2. Effect on Hydrology:_____

_____

_____.

3. Previous Hydrology:_____

(Attach documentation) _____

_____.

4. Wetland Hydrology? Yes_____No_____.

Characterized By:_____

DATA FORM 1

WETLAND DETERMINATION

Applicant Name: John Doe Application Number: R-85-1421 Project Name: Zena Acricultural Land

State: LA County: Choctaw Legal Description: Township: 7N Range: 2E

Date: 10/08/85 Plot No.: 1-1 Section: 32

Vegetation [list the three dominant species in each vegetation layer (5 if only 1 or 2 layers)]. Indicate species with observed morphological or known physiological adaptations with an asterisk.

Species	Indicator Status	Species	Indicator Status
Trees		Herbs	
1. *Quercus lyrata*	OBL	7. *Polygonum hydropiperoides*	OBL
2. *Carya aquatica*	OBL	8. *Boehmeria cylindrica*	FACW+
3. *Gleditsia aquatica*	OBL	9. *Brunnichia cirrhosa*	--
Saplings/shurbs		Woody vines	
4. *Forestiera acuminata*	OBL	10. *Toxicodendron radicans*	FAC
5. *Planera aquatica*	OBL	11. --	--
6. --	--	12. --	--

% of species that are OBL, FACW, and/or FAC: 100%. Other indicators: --.

Hydrophytic vegetation: Yes X No ____. Basis: 50% of dominants are OBL, FACW, and/or FAC on plant list.

Soil

Series and phase: Sharkey, frequently flooded On hydric soils list? Yes X; No ____.

Mottled: Yes X; No ____. Mottle color: 5YR4/6; Matrix color: 10YR4/1.

Gleyed: Yes ____ No X. Other indicators: ____.

Hydric soils: Yes X No ____; Basis: On hydric soil list and matrix color.

Hydrology

Inundated: Yes ____; No X. Depth of standing water: --.

Saturated soils: Yes X; No ____. Depth to saturated soil: 6".

Other indicators: Drift lines and sediment deposits present on trees.

Wetland hydrology: Yes X; No ____. Basis: Saturated soils.

Atypical situation: Yes ____; No X.

Normal Circumstances?: Yes X No ____.

Wetland Determination: Wetland X; Nonwetland ____.

Comments: No rain reported from area in previous two weeks.

Determined by: Zelda Schmell (Signed)

DATA FORM 2

VEGETATION-COMPREHENSIVE DETERMINATION

Applicant Name: John Doe Application No.: R-85-1421 Project Name: Zena Agricultural Land

Location: LA (Choctaw Parish) Plot #: 1-1 Date: 10/08/85 Determined By: Zelda Schmell

VEGETATION LAYER

	TREES	BASAL AREA (in^2)	TOTAL BASAL AREA	RANK
1	*Quercus lyrata*	465	1,145	1
2	*Quercus lyrata*	680		
3	*Carya aquatica*	85	243	3
4	*Carya aquatica*	120		
5	*Carya aquatica*	38		
6	*Gleditsia aquatica*	235	253	2
7	*Gleditsia aquatica*	18		
8	*Diospyros virginiana*	46	46	
9				
10				

	HERBS	MIDPOINT OF % COVER CLASS	RANK
1	*Boehmeria cylindrica*	37.5	2
2	*Polygonum hydropiperoides*	62.5	1
3	*Brunnichia ovata*	37.5	3
4	*Gleditsia aquatica* (seedling)	2.5	
5	*Eclipta alba*	2.5	
6			
7			
8			
9			
10			

	SAPLINGS/SHRUBS	MIDPOINT OF HEIGHT CLASS	TOTAL HEIGHT CLASS	RANK
1	*Forestiera acuminata*	4.5	13.0	1
2	*Forestiera acuminata*	4.5		
3	*Forestiera acuminata*	1.5		
4	*Forestiera acuminata*	2.5		
5	*Planera aquatica*	4.5	8.0	2
6	*Planera aquatica*	3.5		
7	*Carya aquatica*	1.5	1.5	
8				
9				
10				

	WOODY VINES	NUMBER OF STEMS	RANK
1	*Toxicodendron radicans*	35	1
2	(only woody vine present)		
3			
4			
5			
6			
7			
8			
9			
10			

DATA FORM 3

ATYPICAL SITUATIONS

Applicant Name: Wetland Developers, Inc. Application Number: R-85-12 Project Name: Big Canal

Location: Joshua Co., MT Plot Number: 2 Date: 10/08/85

A. VEGETATION:

1. Type of Alteration: Vegetation totally removed or covered by placement of fill from canal (1984).

2. Effect on Vegetation: None remaining.

3. Previous Vegetation: *Carex nebrascensis* - *Juncus effusus* freshwater marsh (based on contiguous plant communities and aerial photography predating fill).
(Attach documentation)

4. Hydrophytic Vegetation? Yes X No .

B. SOILS:

1. Type of Alteration: Original soil covered by 4 feet of fill material excavated from canal.

2. Effect on Soils: Original soil buried in 1984.

3. Previous Soils: Original soil examined at 10 inches below original soil surface. Soil gleyed (color notation 5Y2/0).
(Attach documentation)

4. Hydric Soils? Yes X No .

C. HYDROLOGY:

1. Type of Alteration: 4 feet of fill material placed on original surface.

2. Effect on Hydrology: Area no longer is inundated.

3. Previous Hydrology: Examination of color IR photography taken on 6/5/84 showed the area to be inundated. Gaging station data from gage 2 miles upstream indicated the area has been inundated for as much as 3 months of the growing season during 8 of the past 12 years.
(Attach documentation)

4. Wetland Hydrology? Yes X No .

Characterized By: Joe Zook

Appendix C
Vegetation

1. This appendix contains three sections. ~~Section 1 is a subset of the regional list of plants that occur in wetlands, but includes only those species having an indicator status of OBL, FACW, or FAC. Section 2 is a list of plants that commonly occur in wetlands of a given region. Since many geographic areas of Section 404 responsibility include portions of two or more plant list regions, users will often need more than one regional list; thus, Sections 1 and 2 will be published separately from the remainder of the manual. Users will be furnished all appropriate regional lists.~~

USER NOTES: CE-supplied plant lists are obsolete and have been superseded by the May 1988 version of the "National List of Plant Species that Occur in Wetlands" published by the U.S. Fish and Wildlife Service and available on the World Wide Web. (HQUSACE, 27 Aug 91)

2. Section 3, which is presented herein, describes morphological, physiological, and reproductive adaptations that can be observed or are known to occur in plant species that are typically adapted for life in anaerobic soil conditions.

Section 3 - Morphological, Physiological, and Reproductive Adaptations of Plant Species for Occurrence in Areas Having Anaerobic Soil Conditions

Morphological adaptations

3. Many plant species have morphological adaptations for occurrence in wetlands. These structural modifications most often provide the plant with increased buoyancy or support. In some cases (e.g., adventitious roots), the adaptation may facilitate the uptake of nutrients and/or gases (particularly oxygen). However, not all species occurring in areas having anaerobic soil condi-

tions exhibit morphological adaptations for such conditions. The following is a list of morphological adaptations that a species occurring in areas having anaerobic soil conditions may possess (a partial list of species with such adaptations is presented in Table Cl):

Table C1
Partial List of Species with Known Morphological Adaptations for Occurrence in Wetlands[1]

Species	Common Name	Adaptation
Acer negundo	Box elder	Adventitious roots
Acer rubrum	Red maple	Hypertrophied lenticels
Acer saccharinum	Silver maple	Hypertrophied lenticels; adventitious roots (juvenile plants)
Alisma spp.	Water plantain	Polymorphic leaves
Alternanthera philoxeroides	Alligatorweed	Adventitious roots; inflated, floating stems
Avicennia nitida	Black mangrove	Pneumatophores; hypertrophied lenticels
Brasenia schreberi	Watershield	Inflated, floating leaves
Caladium mariscoides	Twig rush	Inflated stems
Cyperus spp. (most species)	Flat sedge	Inflated stems and leaves
Eleocharis spp. (most species)	Spikerush	Inflated stems and leaves
Forestiera accuminata	Swamp privet	Multi-trunk, stooling
Fraxinus pennsylvanica	Green ash	Buttressed trunks; adventitious roots
Gleditsia aquatica	Water locust	Hypertrophied lenticels
Juncus spp.	Rush	Inflated stems and leaves
Limnobium spongia	Frogbit	Inflated, floating leaves
Ludwigia spp.	Waterprimrose	Adventitious roots; inflated floating stems
Menyanthes trifoliata	Buckbean	Inflated stems (rhizome)
Myrica gale	Sweetgale	Hypertrophied lenticels
Nelumbo spp.	Lotus	Floating leaves
Nuphar spp.	Cowlily	Floating leaves
Nymphaea spp.	Waterlily	Floating leaves
Nyssa aquatica	Water tupelo	Buttressed trunks; pneumatophores; adventitious roots
Nyssa ogechee	Ogechee tupelo	Buttressed trunks; multi-trunk; stooling
Nyssa sylvatica var. *biflora*	Swamp blackgum	Buttressed trunks
Platanus occidentalis	Sycamore	Adventitious roots
Populus deltoides	Cottonwood	Adventitious roots
Quercus laurifolia	Laurel oak	Shallow root system
Quercus palustris	Pin oak	Adventitious roots
Rhizophora mangle	Red mangrove	Pneumatophores
Sagittaria spp.	Arrowhead	Polymorphic leaves
Salix spp.	Willow	Hypertrophied lenticels; adventitious roots; oxygen pathway to roots
Scirpus spp.	Bulrush	Inflated stems and leaves
Spartina alterniflora	Smooth cordgrass	Oxygen pathway to roots
Taxodium distichum	Bald cypress	Buttressed trunks; pneumatophores

[1] Many other species exhibit one or more morphological adaptations for occurrence in wetlands. However, not all individuals of a species will exhibit these adaptations under field conditions, and individuals occurring in uplands characteristically may not exhibit them.

a. Buttressed tree trunks. Tree species (e.g., *Taxodium distichum)* may develop enlarged trunks (Figure Cl) in response to frequent inundation. This adaptation is a strong indicator of hydrophytic vegetation in non-tropical forested areas.

b. Pneumatophores. These modified roots may serve as respiratory organs in species subjected to frequent inundation or soil saturation. Cypress knees (Figure C2) are a classic example, but other species (e.g., *Nyssa aquatica, Rhizophora mangle)* may also develop pneumatophores.



Figure C1. Buttressed tree truck (bald cypress)



Figure C2. Pneumatophores (bald cypress)

c. Adventitious roots. Sometimes referred to as "water roots," adventitious roots occur on plant stems in positions where roots normally are not found. Small fibrous roots protruding from the base of trees (e.g., *Salix nigra)* or roots on stems of herbaceous plants and tree seedlings in positions immediately above the soil surface (e.g., *Ludwigia* spp.) occur in response to inundation or soil saturation (Figure C3). These usually develop during periods of sufficiently prolonged soil saturation to destroy most of the root system. *CAUTION: Not all adventitious roots develop as a result of inundation or soil saturation. For example, aerial roots on woody vines are not normally produced as a response to inundation or soil saturation.*



Figure C3. Adventitious roots

d. Shallow root systems. When soils are inundated or saturated for long periods during the growing season, anaerobic conditions develop in the zone of root growth. Most species with deep root systems cannot survive in such conditions. Most species capable of growth during periods when soils are oxygenated only near the surface have shallow root systems. In forested wetlands,

windthrown trees (Figure C4) are often indicative of shallow root systems.



Figure C4. Wind-thrown tree with shallow root system

e. *Inflated leaves, stems, or roots.* Many hydrophytic species, particularly herbs (e.g., *Limnobium spongia*, *Ludwigia* spp.) have or develop spongy (aerenchymous) tissues in leaves, stems, and/or roots that provide buoyancy or support and serve as a reservoir or passageway for oxygen needed for metabolic processes. An example of inflated leaves is shown in Figure C5.



Figure C5. Inflated leaves

f. *Polymorphic leaves.* Some herbaceous species produce different types of leaves, depending on the water level at the time of leaf formation. For example, *Alisma* spp. produce strap-shaped leaves when totally submerged, but produce broader, floating leaves when plants are emergent. *CAUTION: Many upland species also produce polymorphic leaves.*

g. *Floating leaves.* Some species (e.g., *Nymphaea* spp.) produce leaves that are uniquely adapted for floating on a water surface (Figure C6). These leaves have stomata primarily on the upper surface and a thick waxy cuticle that restricts water penetration. The presence of species with floating leaves is strongly indicative of hydrophytic vegetation.



Figure C6. Floating leaves

h. *Floating stems.* A number of species (e.g., *Alternanthera philoxeroides*) produce matted stems that have large internal air spaces when occurring in inun-

dated areas. Such species root in shallow water and grow across the water surface into deeper areas. Species with floating stems often produce adventitious roots at leaf nodes.

i. *Hypertrophied lenticels.* Some plant species (e.g., *Gleditsia aquatica*) produce enlarged lenticels on the stem in response to prolonged inundation or soil saturation. These are thought to increase oxygen uptake through the stem during such periods.



Figure C7. Multitrunk plant

k. *Multitrunks or stooling.* Some woody hydrophytes characteristically produce several trunks of different ages (Figure C7) or produce new stems arising from the base of a senescing individual (e.g., *Forestiera acuminata, Nyssa ogechee)* in response to inundation.

l. *Oxygen pathway to roots.* Some species (e.g., *Spartina alterniflora*) have a specialized cellular arrangement that facilitates diffusion of gaseous oxygen from leaves and stems to the root system.

Physiological adaptations

4. Most, if not all, hydrophytic species are thought to possess physiological adaptations for occurrence in areas that have prolonged periods of anaerobic soil conditions. However, relatively few species have actually been proven to possess such adaptations, primarily due to the limited research that has been conducted. Nevertheless, several types of physiological adaptations known to occur in hydrophytic species are discussed below, and a list of species having one or more of these adaptations is presented in Table C2. *NOTE: Since it is impossible to detect these adaptations in the field, use of this indicator will be limited to observing the species in the field and checking the list in Table C2 to determine whether the species is known to have a physiological adaptation for occurrence in areas having anaerobic soil conditions.*

Table C2
Species Exhibiting Physiological Adaptations for Occurrence in Wetlands

Species	Physiological Adaptation
Alnus incana	Increased levels of nitrate reductase; malate accumulation
Alnus rubra	Increased levels of nitrate reductase
Baccharis viminea	Ability for root growth in low oxygen tensions
Betula pubescens	Oxidizes the rhizosphere; malate accumulation
Carex arenaria	Malate accumulation
Carex flacca	Absence of ADH activity
Carex lasiocarpa	Malate accumulation
Deschampsia cespitosa	Absence of ADH activity
Filipendula ulmaria	Absence of ADH activity
Fraxinus pennsylvanica	Oxidizes the rhizosphere
Glyceria maxima	Malate accumulation; absence of ADH activity
Juncus effusus	Ability for root growth in low oxygen tensions; absence of ADH activity
Larix laricina	Slight increases in metabolic rates; increased levels of nitrate reductase
Lobelia dortmanna	Oxidizes the rhizosphere
Lythrum salicaria	Absence of ADH activity
Molinia caerulea	Oxidizes the rhizosphere
Myrica gale	Oxidizes the rhizosphere
Nuphar lutea	Organic acid production
Nyssa aquatica	Oxidizes the rhizosphere
Nyssa sylvatica var. *biflora*	Oxidizes the rhizosphere; malate accumulation
Phalaris arundinacea	Absence of ADH activity; ability for root growth in low oxygen tensions
Phragmites australis	Malate accumulation
Pinus contorta	Slight increases in metabolic rates; increased levels of nitrate reductase
Polygonum amphibium	Absence of ADH activity
Potentilla anserina	Absence of ADH activity; ability for root growth in low oxygen tensions
Ranunculus flammula	Malate accumulation; absence of ADH activity
Salix cinerea	Malate accumulation
Salix fragilis	Oxidizes the rhizosphere
Salix lasiolepis	Ability for root growth in low oxygen tensions
Scirpus maritimus	Ability for root growth in low oxygen tensions
Senecio vulgaris	Slight increases in metabolic rates
Spartina alterniflora	Oxidizes the rhizosphere
Trifolia subterraneum	Low ADH activity
Typha angustifolia	Ability for root growth in low oxygen tensions

a. *Accumulation of malate.* Malate, a nontoxic metabolite, accumulates in roots of many hydrophytic species (e.g., *Glyceria maxima*, *Nyssa sylvatica* var. *biflora*). Nonwetland species concentrate ethanol, a toxic by-product of anaerobic respiration, when growing in anaerobic soil conditions. Under such conditions, many hydrophytic species produce high concentrations of malate and unchanged concentrations of ethanol, thereby avoiding accumulation of toxic materials. Thus, species having the ability to concentrate malate instead of ethanol in the root system under anaerobic soil conditions are adapted for life in such conditions, while species that concentrate ethanol are poorly adapted for life in anaerobic soil conditions.

b. *Increased levels of nitrate reductase.* Nitrate reductase is an enzyme involved in conversion of nitrate nitrogen to nitrite nitrogen, an intermediate step in ammonium production. Ammonium ions can accept electrons as a replacement for gaseous oxygen in some species, thereby allowing continued functioning of metabolic processes under low soil oxygen conditions. Species that produce high levels of nitrate reductase (e.g., *Larix laricina*) are adapted for life in anaerobic soil conditions.

c. *Slight increases in metabolic rates.* Anaerobic soil conditions effect short-term increases in metabolic rates in most species. However, the rate of metabolism often increases only slightly in wetland species, while metabolic rates increase significantly in nonwetland species. Species exhibiting only slight increases in metabolic rates (e.g., *Larix laricina, Senecio vulgaris)* are adapted for life in anaerobic soil conditions.

d. *Rhizosphere oxidation.* Some hydrophytic species (e.g., *Nyssa sylvatica, Myrica gale*) are capable of transferring gaseous oxygen from the root system into soil pores immediately surrounding the roots. This adaptation prevents root deterioration and maintains the rates of water and nutrient absorption under anaerobic soil conditions.

e. *Ability for root growth in low oxygen tensions.* Some species (e.g., *Typha angustifolia, Juncus effusus*) have the ability to maintain root growth under soil oxygen concentrations as low as 0.5 percent. Although prolonged (>l year) exposure to soil oxygen concentrations lower than 0.5 percent generally results in the death of most individuals, this adaptation enables some species to survive extended periods of anaerobic soil conditions.

f. *Absence of alcohol dehydrogenase (ADH) activity.* ADH is an enzyme associated with increased ethanol production. When the enzyme is not functioning, ethanol production does not increase significantly. Some hydrophytic species (e.g., *Potentilla anserina, Polygonum amphibium*) show only slight increases in ADH activity under anaerobic soil conditions. Therefore, ethanol production occurs at a slower rate in species that have low concentrations of ADH.

Reproductive adaptations

5. Some plant species have reproductive features that enable them to become established and grow in saturated soil conditions. The following have been identified in the technical literature as reproductive adaptations that occur in hydrophytic species:

a. *Prolonged seed viability.* Some plant species produce seeds that may remain viable for 20 years or more. Exposure of these seeds to atmospheric oxygen usually triggers germination. Thus, species (e.g., *Taxodium distichum)* that grow in very wet areas may produce seeds that germinate only during infrequent periods when the soil is dewatered. *NOTE: Many upland species also have prolonged seed viability, but the trigger mechanism for germination is not exposure to atmospheric oxygen.*

b. *Seed germination under low oxygen concentrations.* Seeds of some hydrophytic species germinate when submerged. This enables germination during periods of early-spring inundation, which may provide resulting seedlings a competitive advantage over species whose seeds germinate only when exposed to atmospheric oxygen.

c. *Flood-tolerant seedlings.* Seedlings of some hydrophytic species (e.g., *Fraxinus pennsylvanica)* can survive moderate periods of total or partial inundation. Seedlings of these species have a competitive advantage over seedlings of flood-intolerant species.

Appendix D
Hydric Soils

1. This appendix consists of two sections. Section 1 describes the basic procedure for digging a soil pit and examining for hydric soil indicators. ~~Section 2 is a list of hydric soils of the United States.~~

Section I - Procedures for Digging a Soil Pit and Examining for Hydric Soil Indicators

Digging a soil pit

2. Apply the following procedure: Circumscribe a 1-ft-diam area, preferably with a tile spade (sharpshooter). Extend the blade vertically downward, cut all roots to the depth of the blade, and lift the soil from the hole. This should provide approximately 16 inches of the soil profile for examination. *NOTE: Observations are usually made immediately below the A-horizon or 10 in. (whichever is shallower).* In many cases, a soil auger or probe can be used instead of a spade. If so, remove successive cores until 16 inches of the soil profile have been removed. Place successive cores in the same sequence as removed from the hole. *NOTE: An auger or probe cannot be effectively used when the soil profile is loose, rocky, or contains a large volume of water (e.g., peraquic moisture regime).*

Examining the soil

3. Examine the soil for hydric soils indicators (paragraphs 44 and/or 45 of main text (for sandy soils)). *NOTE: It may not be necessary to conduct a classical characterization (e.g., texture, structure, etc.) of the soil*. Consider the hydric soil indicators in the following sequence *(NOTE: The soil examination can be terminated when a positive hydric soil indicator is found):*

Nonsandy soils.

a. Determine whether an organic soil is present (see paragraph 44 of the main text). If so, the soil is hydric.

b. Determine whether the soil has a histic epipedon (see paragraph 44 of the main text). Record the thickness of the histic epipedon on Data Form 1.

c. Determine whether sulfidic materials are present by smelling the soil. The presence of a "rotten egg" odor is indicative of hydrogen sulfide, which forms only under extreme reducing conditions associated with prolonged inundation/soil saturation.

d. Determine whether the soil has an aquic or peraquic moisture regime (see paragraph 44 of the main text). If so, the soil is hydric.

e. Conduct a ferrous iron test. A colorimetric field test kit has been developed for this purpose. A reducing soil environment is present when the soil extract turns pink upon addition of α,α'-dipyridyl.

f. Determine the color(s) of the matrix and any mottles that may be present. Soil color is characterized by three features: hue, value, and chroma. Hue refers to the soil color in relation to red, yellow, blue, etc. Value refers to the lightness of the hue. Chroma refers to the strength of the color (or departure from a neutral of the same lightness). Soil colors are determined by use of a Munsell Color Book (Munsell Color 1975).[1] Each Munsell Color Book has color charts of different hues, ranging from 10R to 5Y. Each page of hue has color chips that show values and chromas. Values are shown in columns down the page from as low as 0 to as much as 8, and chromas are shown in rows across the page from as low as 0 to as much as 8. In writing Munsell color notations, the sequence is always hue, value, and chroma (e.g., 10YR 5/2). To determine soil color, place a small portion of soil[2] in the openings behind the color page and match the soil color to the appropriate color chip. *NOTE: Match the soil to the nearest color chip.* Record on DATA FORM 1 the hue, value, and chroma of the best matching color chip. *CAUTION: Never place soil on the face or front of the color page because this might smear the color chips.* Mineral hydric soils usually have one of the following color features immediately below the A-horizon or 10 inches (whichever is shallower):

(1) Gleyed soil.

---

[1] See references at the end of the main text.

[2] The soil must be moistened if dry at the time of examination.

Determine whether the soil is gleyed. If the matrix color best fits a color chip found on the gley page of the Munsell soil color charts, the soil is gleyed. This indicates prolonged soil saturation, and the soil is highly reduced.

(2) Nongleyed soil.

(a) Matrix chroma of 2 or less in mottled soils.[1]

(b) Matrix chroma of 1 or less in unmottled soils.[1]

(c) Gray mottles within 10 in. of the soil surface in dark (black) mineral soils (e.g., Mollisols) that do not have characteristics of (a) or (b) above.

Soils having the above color characteristics are normally saturated for significant duration during the growing season. However, hydric soils with significant coloration due to the nature of the parent material (e.g., red soils of the Red River Valley) may not exhibit chromas within the range indicated above. In such cases, this indicator cannot be used.

g. Determine whether the mapped soil series or phase is on the national list of hydric soils (Section 2). *CAUTION: It will often be necessary to compare the profile description of the soil with that of the soil series or phase indicated on the soil map to verify that the soil was correctly mapped. This is especially true when the soil survey indicates the presence of inclusions or when the soil is mapped as an association of two or more soil series.*

h. Look for iron and manganese concretions. Look for small (>0.08-in.) aggregates within 3 in. of the soil surface. These are usually black or dark brown and reflect prolonged saturation near the soil surface.

Sandy soils.

Look for one of the following indicators in sandy soils:

a. A layer of organic material above the mineral surface or high organic matter content in the surface horizon (see paragraph 45*a* of the main text). This is evidenced by a darker color of the surface layer due to organic matter interspersed among or adhering to the sand particles. This is not observed in upland soils due to associated aerobic conditions.

b. Streaking of subsurface horizons (see paragraph 45*b* of the main text). Look for dark vertical streaks in subsurface horizons. These streaks

[1] The soil must be moistened if dry at the time of examination.

represent organic matter being moved downward in the profile. When soil is rubbed between the fingers, the organic matter will leave a dark stain on the fingers.

c. Organic pans (see paragraph 45*c* of the main text). This is evidenced by a thin layer of hardened soil at a depth of 12 to 30 inches below the mineral surface.

Section 2 - Hydric Soils of the United States

4. The list of hydric soils of the United States ~~(Table D1)~~ was developed by the National Technical Committee for Hydric Soils (NTCHS), a panel consisting of representatives of the Soil Conservation Service (SCS), Fish and Wildlife Service, Environmental Protection Agency, Corps of Engineers, Auburn University, University of Maryland, and Louisiana State University. Keith Young of SCS was committee chairman.

5. The NTCHS developed the following definition of hydric soils:

~~A hydric soil is a soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation (U.S. Department of Agriculture (USDA) Soil Conservation Service 1985, as amended by the NTCHS in December 1986).~~

USER NOTES: The hydric soil definition, criteria, and hydric soil list (Table D1) published in the 1987 Corps Manual are obsolete. Current hydric soil definition, criteria, and lists are available over the World Wide Web from the U.S.D.A. Natural Resources Conservation Service (NRCS). (HQUSACE, 27 Aug 91, 6 Mar 92)

Criteria for hydric soils

6. Based on the above definition, the NTCHS developed the following criteria for hydric soils, and all soils appearing on the list will meet at least one criterion:

a. ~~All Histosols[1] except Folists;~~

b. ~~Soils in Aquic suborders, Aquic subgroups, Albolls suborder, Salorthids great group, or Pell great groups of Vertisols that are:~~

[1] Soil taxa conform to USDA-SCS (1975).

(1) Somewhat poorly drained and have water table less than 0.5 ft from the surface for a significant period (usually a week or more) during the growing season, or

(2) Poorly drained or very poorly drained and have either:

(a) A water table at less than 1.0 ft from the surface for a significant period (usually a week or more) during the growing season if permeability is equal to or greater than 6.0 in/hr in all layers within 20 inches; or

(b) A water table at less than 1.5 ft from the surface for a significant period (usually a week or more) during the growing season if permeability is less than 6.0 in/hr in any layer within 20 inches; or

c. Soils that are ponded for long duration or very long duration during part of the growing season; or

d. Soils that are frequently flooded for long duration or very long duration during the growing season.

7. The hydric soils list was formulated by applying the above criteria to soil properties documented in USDA-SCS (1975) and the SCS Soil Interpretation Records (SOI-5).

Use of the list

8. The list of hydric soils of the United States (Table D1) is arranged alphabetically by soil series. Unless otherwise specified, all phases of a listed soil series are hydric. In some cases, only those phases of a soil series that are ponded, frequently flooded, or otherwise designated as wet are hydric. Such phases are denoted in Table D1 by the following symbols in parentheses after the series name:

F - flooded

FF - frequently flooded

P - ponded

W - wet

D - depressional

9. Drained phases of some soil series retain their hydric properties even after drainage. Such phases are identified in Table D1 by the symbol "DR" in parentheses following the soil series name. In such cases, both the drained and un-

~~drained phases of the soil series are hydric.~~ *CAUTION: Be sure that the profile description of the mapping unit conforms to that of the sampled soil. Also, designation of a soil series or phase as hydric does not necessarily mean that the area is a wetland. An area having a hydric soil is a wetland only if positive indicators of hydrophytic vegetation and wetland hydrology are also present.*

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This document presents approaches and methods for identifying and delineating wetlands for purposes of Section 404 of the Clean Water Act. It is designed to assist users in making wetland determinations using a multiparameter approach. Except where noted in the manual, this approach requires positive evidence of hydrophytic vegetation, hydric soils, and wetland hydrology for a determination that an area is a wetland. The multiparameter approach provides a logical, easily defensible, and technical basis for wetland determinations. Technical guidelines are presented for wetlands, deepwater aquatic habitats, and nonwetlands (uplands).

Hydrophytic vegetation, hydric soils, and wetland hydrology are also characterized, and wetland indicators of each parameter are listed.

Methods for applying the multiparameter approach are described. Separate sections are devoted to preliminary data gathering and analysis, method selection, routine determinations, comprehensive determinations, atypical situations, and problem areas. Three levels of routine determinations are described, thereby affording significant flexibility in method selection.

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Four appendices provide supporting information. Appendix A is a glossary of technical terms used in the manual. Appendix B contains data forms for use with the various methods. Appendix C, developed by a Federal interagency panel, contains a list of all plant species known to occur in wetlands of the region. Each species has been assigned an indicator status that describes its estimated probability of occurring in wetlands of the region. Morphological, physiological, and reproductive adaptations that enable a plant species to occur in wetlands are also described, along with a listing of some species having such adaptations. Appendix D describes the procedure for examining the soil for indicators of hydric soil conditions, and includes a national list of hydric soils developed by the National Technical Committee for Hydric Soils.

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Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Northcentral and Northeast Region

(Version 2.0)

U.S. Army Corps of Engineers

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Abstract: This document is one of a series of Regional Supplements to the Corps of Engineers Wetland Delineation Manual, which provides technical guidance and procedures for identifying and delineating wetlands that may be subject to regulatory jurisdiction under Section 404 of the Clean Water Act or Section 10 of the Rivers and Harbors Act. The development of Regional Supplements is part of a nationwide effort to address regional wetland characteristics and improve the accuracy and efficiency of wetland-delineation procedures. This supplement is applicable to the Northcentral and Northeast Region, which consists of all or portions of 15 states: Connecticut, Illinois, Indiana, Maine, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, and Wisconsin.

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Preface

This document is one of a series of Regional Supplements to the Corps of Engineers Wetland Delineation Manual. It was developed by the U.S. Army Engineer Research and Development Center (ERDC) at the request of Headquarters, U.S. Army Corps of Engineers (USACE), with funding provided through the Wetlands Regulatory Assistance Program (WRAP). This is Version 2.0 of the Northcentral and Northeast Regional Supplement; it replaces the "interim" version, which was published in October 2009.

This document was developed in cooperation with the Northcentral and Northeast Regional Working Group, whose members contributed their time and expertise to the project over a period of many months. Working Group meetings were held in Hanover, NH, on 6-8 November 2007 and Madison, WI, on 15-17 April 2008. Members of the Regional Working Group and contributors to this document were:

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COL Kevin J. Wilson was Commander of ERDC. Dr. Jeffery P. Holland was Director.

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1 Introduction

Purpose and use of this regional supplement

This document is one of a series of Regional Supplements to the Corps of Engineers Wetland Delineation Manual (hereafter called the Corps Manual). The Corps Manual provides technical guidance and procedures, from a national perspective, for identifying and delineating wetlands that may be subject to regulatory jurisdiction under Section 404 of the Clean Water Act (33 U.S.C. 1344) or Section 10 of the Rivers and Harbors Act (33 U.S.C. 403). According to the Corps Manual, identification of wetlands is based on a three-factor approach involving indicators of hydrophytic vegetation, hydric soil, and wetland hydrology. This Regional Supplement presents wetland indicators, delineation guidance, and other information that is specific to the Northcentral and Northeast Region.

This Regional Supplement is part of a nationwide effort to address regional wetland characteristics and improve the accuracy and efficiency of wetland-delineation procedures. Regional differences in climate, geology, soils, hydrology, plant and animal communities, and other factors are important to the identification and functioning of wetlands. These differences cannot be considered adequately in a single national manual. The development of this supplement follows National Academy of Sciences recommendations to increase the regional sensitivity of wetland-delineation methods (National Research Council 1995). The intent of this supplement is to bring the Corps Manual up to date with current knowledge and practice in the region and not to change the way wetlands are defined or identified. The procedures given in the Corps Manual, in combination with wetland indicators and guidance provided in this supplement, can be used to identify wetlands for a number of purposes, including resource inventories, management plans, and regulatory programs. The determination that a wetland is subject to regulatory jurisdiction under Section 404 or Section 10 must be made independently of procedures described in this supplement.

This Regional Supplement is designed for use with the current version of the Corps Manual (Environmental Laboratory 1987) and all subsequent versions. Where differences in the two documents occur, this Regional Supplement takes precedence over the Corps Manual for applications in

the Northcentral and Northeast Region. Table 1 identifies specific sections of the Corps Manual that are replaced by this supplement. Other guidance and procedures given in this supplement and not listed in Table 1 are intended to augment the Corps Manual but not necessarily to replace it. The Corps of Engineers has final authority over the use and interpretation of the Corps Manual and this supplement in the Northcentral and Northeast Region.

Table 1. Sections of the Corps Manual replaced by this Regional Supplement for applications in the Northcentral and Northeast Region.

Item	Replaced Portions of the Corps Manual (Environmental Laboratory 1987)	Replacement Guidance (this Supplement)
Hydrophytic Vegetation Indicators	Paragraph 35, all subparts, and all references to specific indicators in Part IV.	Chapter 2
Hydric Soil Indicators	Paragraphs 44 and 45, all subparts, and all references to specific indicators in Part IV.	Chapter 3
Wetland Hydrology Indicators	Paragraph 49(b), all subparts, and all references to specific indicators in Part IV.	Chapter 4
Growing Season Definition	Glossary	Chapter 4, Growing Season; Glossary
Hydrology Standard for Highly Disturbed or Problematic Wetland Situations	Paragraph 48, including Table 5 and the accompanying User Note in the online version of the Manual	Chapter 5, Wetlands that Periodically Lack Indicators of Wetland Hydrology, Procedure item 3(f)

Indicators and procedures given in this Supplement are designed to identify wetlands as defined jointly by the Corps of Engineers (33 CFR 328.3) and Environmental Protection Agency (40 CFR 230.3). Wetlands are a subset of the "waters of the United States" that may be subject to regulation under Section 404. One key feature of the definition of wetlands is that, under normal circumstances, they support "a prevalence of vegetation typically adapted for life in saturated soil conditions." Many waters of the United States are unvegetated and thus are excluded from the Corps/EPA definition of wetlands, although they may still be subject to Clean Water Act regulation. Other potential waters of the United States in the region include, but are not limited to, tidal flats and shorelines along the Atlantic coast, in estuaries, and along the shores of the Great Lakes; unvegetated temporary pools; ponds; lakes; mud flats; and perennial, intermittent, and ephemeral stream channels. Delineation of these waters

is based on the high tide line, the "ordinary high water mark" (33 CFR 328.3e), or other criteria and is beyond the scope of this Regional Supplement.

Amendments to this document will be issued periodically in response to new scientific information and user comments. Between published versions, Headquarters, U.S. Army Corps of Engineers may provide updates to this document and any other supplemental information used to make wetland determinations under Section 404 and Section 10. Wetland delineators should use the most recent approved versions of this document and supplemental information. See the Corps of Engineers Headquarters regulatory web site for information and updates (http://www.usace.army.mil/-CECW/Pages/reg_supp.aspx). The Corps of Engineers has established an interagency National Advisory Team for Wetland Delineation. The Team's role is to review new data and make recommendations for changes in wetland-delineation procedures to Headquarters, U.S. Army Corps of Engineers. Items for consideration should include full documentation and supporting data and should be submitted to:

National Advisory Team for Wetland Delineation
Regulatory Branch (Attn: CECW-CO)
U.S. Army Corps of Engineers
441 G Street, N.W.
Washington, DC 20314-1000

Applicable region and subregions

This supplement is applicable to the Northcentral and Northeast Region, which consists of all or portions of 15 states: Connecticut, Illinois, Indiana, Maine, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, and Wisconsin (Figure 1). The region encompasses considerable topographic and climatic diversity, but is differentiated from surrounding regions mainly by the combination of a humid temperate climate with cold, snowy winters, short growing seasons, and seasonally frozen soils in many areas; glacially sculpted landscape; hardwood, conifer, mixed-forest, and hardwood-savanna natural vegetation; and the preponderance of forest, crop, pasture, and developed land uses (Bailey 1995, USDA Natural Resources Conservation Service 2006).

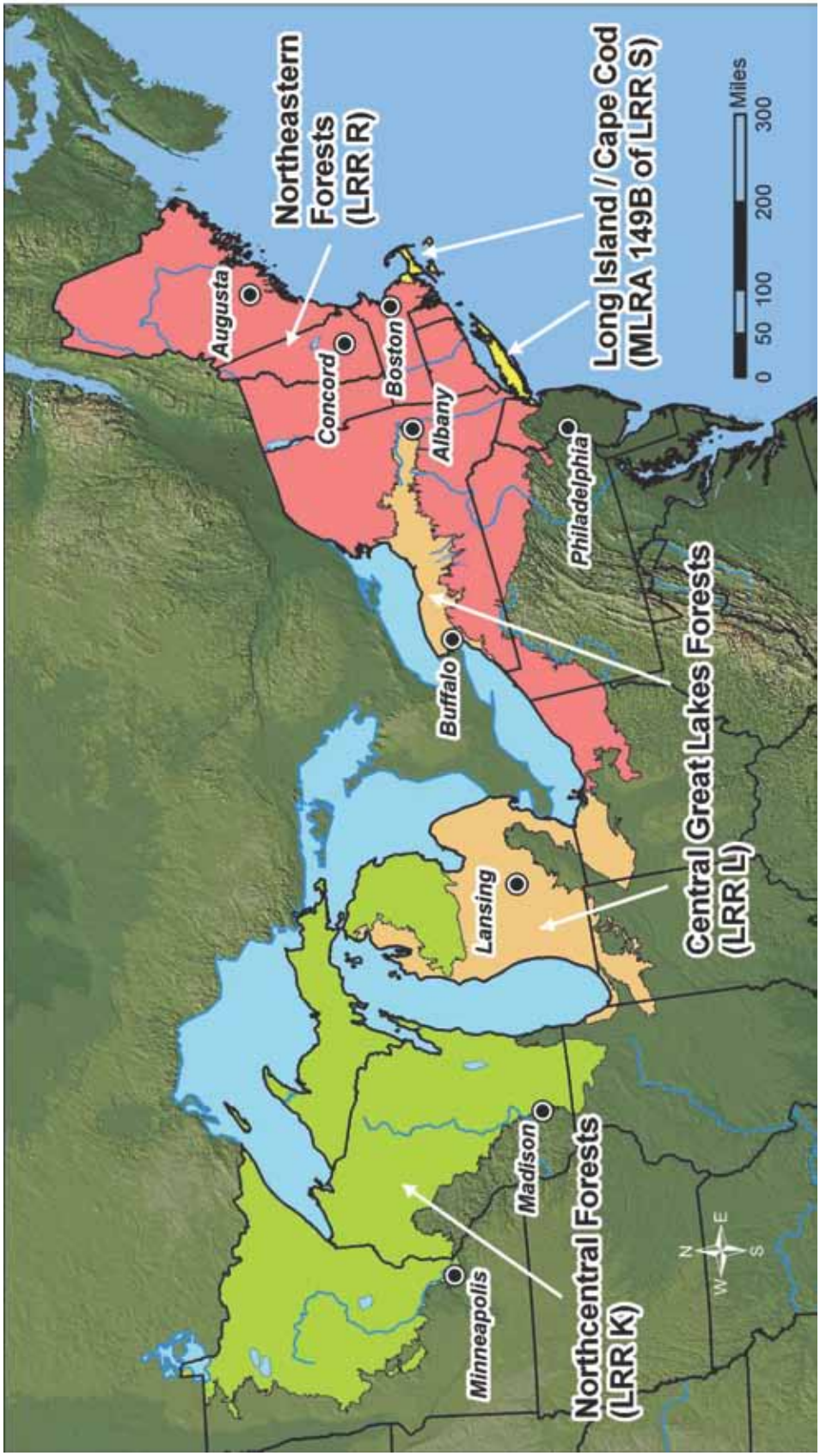


Figure 1. Approximate boundaries of the Northcentral and Northeast Region. Subregions used in this supplement correspond to USDA Land Resource Regions (LRR). This supplement is applicable throughout the highlighted areas, although some indicators may be restricted to specific subregions or smaller areas. See text for details.

The approximate spatial extent of the Northcentral and Northeast Region is shown in Figure 1. The region map is based on a combination of Land Resource Regions (LRR) K, L, and R, and Major Land Resource Area (MLRA) 149B in LRR S, as recognized by the U.S. Department of Agriculture (USDA Natural Resources Conservation Service 2006). Most of the wetland indicators presented in this supplement are applicable throughout the entire Northcentral and Northeast Region. However, some indicators are restricted to specific subregions (i.e., LRRs) or smaller areas (i.e., MLRAs).

Region and subregion boundaries are depicted in Figure 1 as sharp lines. However, climatic conditions and the physical and biological characteristics of landscapes do not change abruptly at the boundaries. In reality, regions and subregions often grade into one another in broad transition zones that may be tens or hundreds of miles wide. The lists of wetland indicators presented in these Regional Supplements may differ between adjoining regions or subregions. In transitional areas, the investigator must use experience and good judgment to select the supplement and indicators that are appropriate to the site based on its physical and biological characteristics. Wetland boundaries are not likely to differ between two supplements in transitional areas, but one supplement may provide more detailed treatment of certain problem situations encountered on the site. If in doubt about which supplement to use in a transitional area, apply both supplements and compare the results. For additional guidance, contact the appropriate Corps of Engineers District Regulatory Office. Contact information for District regulatory offices is available at the Corps Headquarters web site (http://www.usace.army.mil/CECW/Pages/reg_districts.aspx).

Physical and biological characteristics of the region

The Northcentral and Northeast Region is a vast area of nearly level to mountainous terrain, ranging from sea level to 6,288 ft (1,917 m) at Mount Washington in New Hampshire. During the Wisconsinan stage of Pleistocene glaciation, nearly all of the region was covered by continental ice sheets. It is a region of warm summers and cold, snowy winters, with average annual temperatures ranging from 39 to 49 °F (4 to 10 °C) except along the immediate coast. Average annual precipitation varies from 26 to 62 in. (660 to 1,575 mm), depending upon location, and exceeds annual evapotranspiration. In general, precipitation increases across the region from west to east. In Minnesota and Wisconsin, most precipitation occurs in spring and summer; in the rest of the region, precipitation is more

evenly distributed throughout the year (Bailey 1995, USDA Natural Resources Conservation Service 2006). The combination of relatively abundant rainfall, low evapotranspiration, and varied topography has created a region rich in perennial, intermittent, and ephemeral streams, natural lakes, and wetlands.

Soil parent materials in the Northcentral and Northeast Region are predominantly the result of Pleistocene glaciations. Glaciers and meltwater shaped the landscape of the region and deposited the debris as glacial landforms, including moraines, drumlins, eskers, outwash plains, kettles, lake plains, deltas, and other features (Embleton and King 1968). Nearly every landscape in the region has been smoothed by glacial ice and has some sort of glacial material on its surface.

Glacial features can be categorized into two broad groups: ice-contact deposits and glaciofluvial or meltwater deposits. Till is the most extensive ice-contact deposit in the region. It is an unsorted mixture of fine particles, sand, gravel, cobbles, and boulders that was scoured and redeposited by ice (Embleton and King 1968). Deposits are generally thickest in valleys and thinnest over highlands. The properties of glacial till are directly related to the source materials. Till from granitic bedrock is commonly rocky, sandy, and acidic. Till from Mesozoic rocks can be reddish in color, and that derived from former lake plains can be very clayey. Ground moraine is a landform of low relief consisting of basal till deposited by receding ice. The topography is often gently rolling, with numerous shallow depressions. Terminal and lateral moraines are ridges or chains of hills that formed at the ends and sides of glaciers, respectively. For example, Long Island in New York was formed, in part, by the terminal moraine marking the southernmost extent of Wisconsinan glaciers. Drumlins are elongated, streamlined hills of glacial till. They occur in groups oriented parallel to the direction of glacial flow and number in the thousands in some areas. Extensive drumlin fields are found in northwestern New York, east-central Wisconsin, and south-central New England. Slope wetlands are associated with drumlins and other ice-contact deposits throughout the region as a result of water perching in the spring over dense glacial till. Eskers are long narrow ridges composed of stratified sand and gravel deposited by streams flowing through tunnels within and beneath glaciers (Embleton and King 1968; Martini et al. 2001).

Glaciofluvial deposits are formed of materials transported by glacial meltwater. They tend to be sorted by particle size, forming stratified deposits. Meltwater emerging from beneath a glacier often forms braided streams that deposit sand and gravel over a broad area, producing an outwash plain. As glaciers recede, blocks of ice may be isolated and partly buried in the accumulating sediments. As these blocks melt, the unsupported glacial sediments collapse and form depressions called kettles (Embleton and King 1968). Walden Pond in Massachusetts is one example. Some outwash plains are dotted with numerous kettles and are known as pitted outwash. In the Northcentral and Northeast Region, numerous wetlands exist today where kettle holes intercept the regional water table. The finer particles in glacial meltwater may be deposited farther downstream and in the still waters of glacial lakes. Lake (lacustrine) deposits include horizontal strata of silts and clays that accumulate on lake bottoms, and deltas of sandy materials deposited at the mouths of incoming streams. Lacustrine deposits in some areas support complexes of small, rainwater-fed depressional wetlands (Stone and Ashley 1992). In other areas, such as in northern Minnesota, extensive organic soils have formed on glacial lake plains.

Post-glacial, clayey, marine deposits exist in the Champlain Valley of Vermont and along the Atlantic coast from southeastern Massachusetts north to Canada. In Maine, marine deposits occur at elevations up to 420 ft (128 m) above sea level, as a result of post-glacial isostatic (crustal) rebound (Maine Geological Survey 2005). These clayey deposits can be somewhat confusing for wetland delineation as they commonly have gray, lithochromic (inherited from parent material) colors. In addition, wind-blown deposits of silt and fine sand (loess) form a surface cap over glacial materials in some soils in the region. Other parent materials in the region include sand dunes adjacent to the Great Lakes and the Atlantic coast, and recent alluvial deposits along the Mississippi, Hudson, Connecticut, and other rivers.

The Northcentral and Northeast Region occupies the transition zone between the boreal forest to the north and broadleaf deciduous forest to the south. Individual forest stands may consist primarily of conifers, hardwoods, or a mixture of the two. Pines (*Pinus* spp.) and other conifers often dominate in areas with nutrient-poor soils or recent disturbance by fire or human activity. Areas with nutrient-rich soils are often dominated by hardwoods, such as sugar maple (*Acer saccharum*), American basswood (*Tilia americana*), and American beech (*Fagus grandifolia*) (Bailey 1995).

In the mountainous areas of New York and the New England states, there is distinct altitudinal zonation of forest types.

The Northcentral and Northeast Region is composed of three major subregions: Northcentral Forests (corresponds to LRR K), Central Great Lakes Forests (LRR L), and Northeastern Forests (LRR R). In addition, the Long Island/Cape Cod area (MLRA 149B in LRR S) has been included in this region because of its similar climate, geologic history, and soil parent materials (Figure 1). Important characteristics of each subregion are described briefly below; further details can be found in USDA Natural Resources Conservation Service (2006). Wetland indicators presented in this Regional Supplement are applicable across all subregions unless otherwise noted.

Northcentral Forests (LRR K)

This subregion lies mainly south and west of the western Great Lakes in Minnesota, Wisconsin, Michigan, and Illinois (Figure 1) and is covered mostly by level to gently rolling deposits of glacial till, loess, outwash, and glacial lake sediments. The subregion receives 26 to 34 in. (660 to 865 mm) of precipitation each year. The area is largely forested, with lesser amounts of cropland, grassland, and urban development. Common tree species in higher landscape positions include eastern white pine (*Pinus strobus*), red pine (*P. resinosa*), jack pine (*P. banksiana*), eastern hemlock (*Tsuga canadensis*), American beech, yellow birch (*Betula alleghaniensis*), paper birch (*B. papyrifera*), northern red oak (*Quercus rubra*), white oak (*Q. alba*), sugar maple, white ash (*Fraxinus americana*), and quaking aspen (*Populus tremuloides*). Lowlands are dominated mainly by black spruce (*Picea mariana*), tamarack (*Larix laricina*), northern white cedar or arborvitae (*Thuja occidentalis*), balsam fir (*Abies balsamea*), black ash (*Fraxinus nigra*), green ash (*F. pennsylvanica*), silver maple (*Acer saccharinum*), red maple (*A. rubrum*), American elm (*Ulmus americana*), and swamp white oak (*Q. bicolor*) (USDA Natural Resources Conservation Service 2006).

Central Great Lakes Forests (LRR L)

This subregion contains most of Lower Michigan along with portions of Illinois, Indiana, Ohio, Pennsylvania, and New York (Figure 1). It consists of nearly level to gently rolling glacial plains covered by till, outwash, and glacial lake sediments with scattered moraine hills. Most of the area

receives 30 to 41 in. (760 to 1,040 mm) of precipitation each year, with higher amounts in the small area southeast of Lake Erie. The subregion supports mainly broadleaf deciduous forests dominated by bitternut hickory (*Carya cordiformis*), shagbark hickory (*C. ovata*), white oak, northern red oak, black oak (*Quercus velutina*), sugar maple, red maple, American beech, American elm, and American basswood. Eastern white pine, red pine, and jack pine are common species in the portion of the subregion in northwestern Lower Michigan (USDA Natural Resources Conservation Service 2006).

Northeastern Forests (LRR R)

This large subregion extends from northern Ohio to New Jersey to Maine (Figure 1) and encompasses a variety of landforms, including rugged mountains and highly dissected plateaus and plains. Most of the area is covered by a mantle of glacial till, outwash sands and gravels, and glacial lake sediments. Eskers, kames, and drumlins are common features in some areas. Deposits of recent alluvium are present along major rivers, and marine sediments are common along the coast and in the lower portions of river valleys. In the mountains, some areas are dominated by talus and exposed igneous and metamorphic bedrock. Average annual precipitation mostly ranges from 34 to 62 in. (865 to 1,575 mm), but is more than 100 in. (2,540 mm) on the highest peaks in Vermont and New Hampshire, and in the area of lake-effect snows east of Lake Ontario. The subregion supports a mosaic of northern hardwood, spruce, fir, and pine forests. Common species include American beech, paper birch, yellow birch, sugar maple, oaks, eastern hemlock, balsam fir, red spruce (*Picea rubens*), black spruce, eastern white pine, and quaking aspen (USDA Natural Resources Conservation Service 2006).

Long Island/Cape Cod (MLRA 149B)

This area is restricted to New York, Massachusetts, and Rhode Island and is part of LRR S, but is included in the Northcentral and Northeast Region (Figure 1). The area is formed of deep glacial outwash deposits of sand and gravel, mostly covered by a layer of glacial till. Moraines form scattered low hills and ridges. The area receives 41 to 48 in. (1,040 to 1,220 mm) of precipitation each year. Much of the area is developed. Native forests support pitch pine (*Pinus rigida*), eastern white pine, northern red oak, red maple, American beech, yellow birch, and other tree species (USDA Natural Resources Conservation Service 2006).

Types and distribution of wetlands

The Northcentral and Northeast Region is rich in wetlands, due in large part to plentiful precipitation, low evapotranspiration, and diverse landscapes resulting from its recent glacial history. Some of the places where wetlands have formed include (1) shores of the region's many lakes and ponds, (2) broad flats on former glacial lake plains, (3) kettle depressions where ice blocks were left on the landscape as the glaciers retreated, (4) depressions and blocked drainages formed by morainal deposits, (5) outwash deposits of sand and gravel where groundwater discharges or is often near the surface, and (6) deposits of unsorted glacial till that have created relatively impermeable subsoils on flats and slopes. The region also contains large river systems that periodically flood low-lying areas, creating floodplain wetlands of various types. Coastal marshes and dune/swale wetlands have also formed along the Atlantic coast, in estuaries, and along the shores of the Great Lakes. Generalized descriptions of the region's wetlands can be found in Curtis (1971), Eggers and Reed (1997), and Tiner (2005). Additional details on wetland plant communities are given in state natural heritage program reports (e.g., Reschke 1990, Minnesota Department of Natural Resources 2003, and Sperduto 2005) and National Wetlands Inventory (NWI) state reports for Rhode Island and Connecticut (Tiner 1989; Metzler and Tiner 1992). Specific wetland types are described by Johnson (1985), Wright et al. (1992), Tiner (2008), and many others.

Wetlands in the region can be divided broadly into freshwater and saltwater wetlands. Most saltwater wetlands in the region are dominated by herbaceous emergent plants. Freshwater wetlands, on the other hand, can be categorized as forested, shrub-dominated, or herbaceous, and further subdivided by soil type (e.g., mineral or organic) and hydrology. For example, various types of bogs are common in the region. Bogs are peat-forming wetlands with acidic soils that support relatively few species of acid-loving plants, such as *Sphagnum* mosses, and develop in areas where precipitation is the primary water source. Other peat-forming wetlands, called fens, have circumneutral to alkaline soils that range from mineral-poor to mineral-rich. Their hydrology is driven predominantly by groundwater discharge and their plant communities can be very diverse.

Forested wetlands are the most abundant wetlands in the region and represent many different types. Boreal coniferous forested wetlands occur in the more northerly parts of the region and at higher elevations in more

southerly areas. They may support black spruce, tamarack, balsam fir, northern white cedar, Atlantic white cedar (*Chamaecyparis thyoides*), or red spruce. Coniferous forested bogs include tamarack and black spruce bogs, and usually have a continuous carpet of *Sphagnum*. Those forming on neutral to alkaline peat soils, such as northern white cedar swamps, lack the carpet of *Sphagnum* but may have a rich understory of other bryophytes. Forested fens with similar mineral-rich peat soils often support northern white cedar and tamarack. Eastern hemlock, eastern white pine, and pitch pine also dominate coniferous forested wetlands in various parts of the region.

Deciduous forested wetlands are common throughout much of the region in depressions, on floodplains, on flats on glacial lake plains, and along lake shores. Dominant swamp trees include red maple, black ash, green ash, and pin oak (*Quercus palustris*). Skunk cabbage (*Symplocarpus foetidus*), several species of ferns (e.g., cinnamon [*Osmunda cinnamomea*], royal [*O. regalis*], sensitive [*Onoclea sensibilis*], and eastern marsh fern [*Thelypteris palustris*]), and numerous shrubs (e.g., highbush blueberry [*Vaccinium corymbosum*], alders [*Alnus* spp.], arrowwood [*Viburnum dentatum*], withe-rod [*V. nudum* var. *cassinoides*], red-osier dogwood [*Cornus sericea = C. stolonifera*] and silky dogwood [*C. amomum*]) are common in many swamps. Floodplain forests occupy lowlands adjacent to the larger rivers in the region. Silver maple, eastern cottonwood (*Populus deltoides*), American sycamore (*Platanus occidentalis*), American elm, black willow (*Salix nigra*), and balsam poplar (*Populus balsamifera*) are characteristic bottomland trees, while ostrich fern (*Matteuccia struthiopteris*), false nettle (*Boehmeria cylindrica*), and Canadian woodnettle (*Laportea canadensis*) are common herbs. Other important wetland trees include yellow birch, black gum (*Nyssa sylvatica*), swamp white oak, and quaking aspen. Wet flatwoods occur on broad, glacial lake plains, such as those along Lake Ontario. These wetlands are dominated by typical swamp species, but are not flooded as long as most swamps. Instead, they have seasonally high or perched water tables that may persist from winter to early summer.

Shrub bogs are prominent in northern areas, while deciduous shrub swamps are common throughout the region. Typical shrub-bog species that grow on acidic peat soils in association with a mat of *Sphagnum* mosses include evergreen members of the heath family, such as leatherleaf (*Chamaedaphne calyculata*), bog laurel (*Kalmia polifolia*), bog rosemary

(*Andromeda polifolia* var. *glaucophylla* = *A. glaucophylla*), Labrador tea (*Ledum groenlandicum*), and cranberries (*Vaccinium macrocarpon* and *V. oxycoccos*), as well as sweetgale (*Myrica gale*), black spruce, tamarack, purple pitcher plant (*Sarracenia purpurea*), sundews (*Drosera* spp.), bog aster (*Oclemena nemoralis* = *Aster nemoralis*), bog goldenrod (*Solidago uliginosa*), and threeleaf false lily-of-the-valley (*Maianthemum trifolium* = *Smilacina trifolia*). Characteristic species of deciduous shrub swamps are alders (*Alnus incana* and *A. serrulata*), willows (*Salix* spp.), dogwoods, swamp rose (*Rosa palustris*), steeplebush (*Spiraea tomentosa*), white meadowsweet (*Spiraea alba*), and buttonbush (*Cephalanthus occidentalis*). The ground layer can be composed of a diversity of ferns, sedges, rushes, and forbs, such as those listed below in the paragraph describing wet meadows. The ground layer in disturbed, deciduous shrub swamps may be composed of reed canarygrass (*Phalaris arundinacea*) or other invasive species.

Herbaceous wetlands include marshes, wet meadows, and fens. Two basic types of marshes are found in the region – freshwater and saline marshes. The former occur throughout the region in lakes, ponds, shallow slow-flowing rivers, and isolated depressions, while the latter are found in the intertidal zone of estuaries.

Freshwater marshes, both tidal and nontidal, are generally represented by cattails (*Typha latifolia* and *T. angustifolia*), pickerelweed (*Pontederia cordata*), arrowheads (*Sagittaria* spp.), yellow pond-lily (*Nuphar lutea*), white waterlily (*Nymphaea odorata*), softstem bulrush (*Schoenoplectus tabernaemontani* = *Scirpus validus*), bur-reeds (*Sparganium* spp.), and wild rice (*Zizania aquatica* and *Z. palustris*). Bayonet rush (*Juncus militaris*) grows in shallow water along sandy lake shores. Common reed (*Phragmites australis*) dominates many disturbed freshwater and brackish marshes.

Salt and brackish marshes are dominated by halophytes or salt-tolerant species. Smooth cordgrass (*Spartina alterniflora*) occupies the low marsh that is flooded at least daily by the tides. The high marsh is more diverse, with saltmeadow cordgrass (*Spartina patens*), salt grass (*Distichlis spicata*), and black grass (*Juncus gerardii*) being most common, while switch grass (*Panicum virgatum*) and the shrubby marsh-elder (*Iva frutescens*) often form the marsh border. Other species characteristic of salt marshes include seaside goldenrod (*Solidago sempervirens*), salt-

marsh aster (*Symphyotrichum tenuifolium = Aster tenuifolius*), saltmarsh bulrush (*Schoenoplectus robustus = Scirpus robustus*), and rose mallow (*Hibiscus moscheutos*); these species become more abundant and dominate brackish marshes upstream.

Herbaceous fens occur in northern portions of the region and elsewhere at higher altitudes where they are less common. Fen species at the most mineral-rich end of the gradient include many calciphiles that thrive in soils with higher pH. They include numerous herbs, such as marsh muhly (*Muhlenbergia glomerata*), bluejoint grass (*Calamagrostis canadensis*), twig rush (*Cladium mariscoides*), several sedges (*Carex flava*, *C. sterilis*, *C. lasiocarpa*, *C. lacustris*, *C. stricta*, and *C. utriculata*), thinleaf cotton-sedge (*Eriophorum viridicarinatum*), moor rush (*Juncus stygius*), grass-of-Parnassus (*Parnassia glauca*), purple avens (*Geum rivale*), white lady's slipper (*Cypripedium candidum*), and marsh cinquefoil (*Comarum palustre = Potentilla palustris*), plus several shrubs including shrubby cinquefoil (*Dasiphora fruticosa* ssp. *floribunda = Potentilla fruticosa*), alderleaf buckthorn (*Rhamnus alnifolia*), sageleaf willow (*Salix candida*), autumn willow (*S. serissima*), bog birch (*Betula pumila*), sweetgale, speckled alder (*Alnus incana*), and red-osier dogwood. Minerotrophic moss species (e.g., *Drapanocladus aduncus* and *Campylium stellatum*) may or may not be present.

Wet meadows occur on seasonally saturated mineral or organic soils that may be associated with high water tables and/or surface water inputs. They may be characterized by (1) a single species, such as reed canary-grass, bluejoint grass, or sweetflag (*Acorus calamus*); (2) various sedges, such as tussock sedge (*Carex stricta*), lake sedge (*C. lacustris*), green bulrush (*Scirpus atrovirens*), and woolgrass (*Scirpus cyperinus*), that can be described as a sedge-meadow subtype; or (3) a diverse assemblage of plants including many flowering herbs. Among the more common flowering herbs are Joe-Pye-weeds (*Eupatoriadelphus* spp.), boneset (*Eupatorium perfoliatum*), square-stem monkeyflower (*Mimulus ringens*), asters (e.g., *Symphyotrichum puniceum* [= *Aster puniceus*], *S. lateriflorum*, *S. lanceolatum*, *S. novi-belgii*, *Doellingeria umbellata* [= *Aster umbellatus*]), goldenrods (*Euthamia* spp. and *Solidago* spp.), fringed loosestrife (*Lysimachia ciliata*), swamp candles (*L. terrestris*), irises (*Iris* spp.), jewelweed (*Impatiens capensis* and *I. pallida*), beggar-ticks (*Bidens* spp.), swamp milkweed (*Asclepias incarnata*), blue vervain (*Verbena hastata*), ironweeds (*Vernonia* spp.), and willow-herbs (*Epilo-*

bium spp.). Many wet meadows occur in agricultural areas where they are often used as pasture.

Many wetlands are used for agricultural purposes, including commercial cranberry bogs, farmed mucklands, wild rice impoundments, farmed floodplains, and sod fields. Commercial cranberry bogs generally were constructed from existing wetlands but, more recently, have been created in sandy uplands by excavating to a depth where the water table is at or near the surface for extended periods. These bogs are diked and water levels controlled by irrigation or dewatering. Farmed mucklands were created from hardwood swamps, tamarack swamps, and sedge meadows. After removing natural vegetation, diking, and draining through the use of pumps and siphons, their productive organic soils are planted with a variety of crops including onions, lettuce, celery, and carrots. In Minnesota, wetlands have been converted to impoundments for cultivating wild rice (*Zizania palustris*). Many floodplains in the region have been converted to row crops (e.g., corn or soybeans) and some of these are flooded often enough and long enough to meet wetland standards. Sod fields managed to produce lawn or turf grasses, predominantly Kentucky bluegrass (*Poa pratensis*), are often constructed in wetlands where the surface water is drained by ditches and groundwater levels are closely managed.

Numerous nonnative and/or invasive species have replaced native species and reduced plant diversity in one or more wetland types in the region. Among the problematic herbs are common reed, reed canarygrass, cattails (e.g., *Typha* × *glauca*), purple loosestrife (*Lythrum salicaria*), Japanese stiltgrass (*Microstegium vimineum* = *Eulalia viminea*), garlic mustard (*Alliaria petiolata*), and Japanese knotweed (*Fallopia japonica* = *Polygonum cuspidatum*) plus three aquatic species – water chestnut (*Trapa natans*), curly pondweed (*Potamogeton crispus*), and Eurasian watermilfoil (*Myriophyllum spicatum*). Major invasive woody plants include common buckthorn (*Rhamnus cathartica*), glossy buckthorn (*Frangula alnus* = *Rhamnus frangula*), multiflora rose (*Rosa multiflora*), non-native honeysuckles (*Lonicera* spp.), and Japanese barberry (*Berberis thunbergii*).

2 Hydrophytic Vegetation Indicators

Introduction

The Corps Manual defines hydrophytic vegetation as the community of macrophytes that occurs in areas where inundation or soil saturation is either permanent or of sufficient frequency and duration to influence plant occurrence. The manual uses a plant-community approach to evaluate vegetation. Hydrophytic vegetation decisions are based on the assemblage of plant species growing on a site, rather than the presence or absence of particular indicator species. Hydrophytic vegetation is present when the plant community is dominated by species that require or can tolerate prolonged inundation or soil saturation during the growing season. Hydrophytic vegetation in the Northcentral and Northeast Region is identified by using the indicators described in this chapter.

Many factors besides site wetness affect the composition of the plant community in an area, including regional climate, local weather patterns, topography, soils, natural and human-caused disturbances, and current and historical plant distributional patterns at various spatial scales. Braun (1950) described the vegetation of this region as "... a complex vegetation unit most conspicuously characterized by the prevalence of the deciduous habit of most of its woody constituents. This gives to it a certain uniformity of physiognomy, with alternating summer green and winter leafless aspects. Evergreen species, both broad-leaved and needle-leaved, occur in the arboreal and shrub layers, particularly in seral stages and in marginal and transitional areas." The vegetation reflects the region's glacial past and the most recent retreat of continental glaciers about 10,000 years ago. Freshly exposed tills and bedrock areas were originally dominated by boreal coniferous forest (Davis 1981), which was later replaced mostly by deciduous forests from the west and south of the region and by prairies penetrating eastward (Barbour and Billings 1988). The migration of past and present vegetation across this topographically and climatically varied region has resulted in a highly diverse flora. The regional flora contains more than 4,000 vascular plant species (Stein et al. 2000), of which approximately 2,800 species occur in wetlands to some degree (Reed 1988).

Human disturbances and land-use patterns have affected some parts of the region more than others. Prior to European settlement, Native Ameri-

cans used fire to clear underbrush in forested areas and woody vegetation from grasslands, but their activities had little long-lasting impact (Russell 1983). Greater impacts occurred in the 1800s due to extensive logging for pine and hemlock, clearing of forests for homesteading and grazing, and the beginning of a long-term trend in conversion of forest to agriculture and urban development. These major land-use changes have increased the number and occurrence of "weedy" species in the flora. More than 30 percent of the flora in many parts of the region now consists of non-native species (Stuckey and Barkley 1993).

The characteristics of wetland plant communities in the region are also affected by seasonal changes in availability of water, short- and long-term droughts, and natural and human-caused disturbances (e.g., floods, fires, grazing). Wetlands subject to seasonal hydrology in the region include wet meadows, springs, seeps, seasonal ponds, vernal pools, and floodplain forested wetlands. These wetlands often exhibit seasonal shifts in vegetation composition, potentially changing the status of the community from hydrophytic during the wet season to non-hydrophytic during the dry season. Long-term climatic fluctuations (e.g., multi-year droughts) and fluctuations in lake and sea levels can also change the composition of plant communities over longer periods (Barkley 1986). Woody shrubs and trees in wetlands are often resistant to droughts, while herbaceous vegetation may show dramatic turnover in species composition from drought years to pluvial years. See Chapter 5 for discussions of these and other problematic vegetation situations in the region.

Hydrophytic vegetation decisions are based on the wetland indicator status (Reed [1988] or current approved list) of species that make up the plant community. Species in the facultative categories (FACW, FAC, and FACU) are recognized as occurring in both wetlands and uplands to varying degrees. Although most wetlands are dominated mainly by species rated OBL, FACW, and FAC, some wetland communities may be dominated primarily by FACU species and cannot be identified by dominant species alone. In those cases, other indicators of hydrophytic vegetation must also be considered, particularly where indicators of hydric soils and wetland hydrology are present. This situation is not necessarily due to inaccurate wetland indicator ratings; rather, it is due to the broad tolerances of certain plant species that allow them to be widely distributed across the moisture gradient. Therefore, for some species, it is difficult to

assign a single indicator status rating that encompasses all of the various landscape and ecological settings it can occupy.

Hydrophytic vegetation indicators and procedures presented in this chapter are designed to identify the majority of wetland plant communities in the region. However, some wetland communities may lack any of these indicators. These situations are considered in Chapter 5 (Difficult Wetland Situations in the Northcentral and Northeast Region).

Guidance on vegetation sampling and analysis

General guidance on sampling of vegetation for wetland-delineation purposes is given in the Corps Manual. Those procedures are intended to be flexible and may need to be modified for application in a given region or on a particular site. Vegetation sampling done as part of a routine wetland delineation is designed to characterize the site in question rapidly. A balance must be established between the need to accomplish the work quickly and the need to characterize the site's heterogeneity accurately and at an appropriate scale. The following guidance on vegetation sampling is intended to supplement the Corps Manual for applications in the Northcentral and Northeast Region.

The first step is to identify the major landscape or vegetation units so that they can be evaluated separately. This may be done in advance using an aerial photograph or topographic map, or by walking the site. In general, routine wetland determinations are based on visual estimates of percent cover of plant species that can be made either (1) within the vegetation unit as a whole, or (2) within one or more sampling plots established in representative locations within each unit. Percent cover estimates are more accurate and repeatable if taken within a defined plot. This also facilitates field verification of another delineator's work. The sizes and shapes of plots, if used, may be modified as appropriate to adapt to site conditions and should be recorded on the field data form. When sampling near a plant community boundary, and particularly near the wetland boundary, it may be necessary to adjust plot size or shape to avoid overlapping the boundary and extending into an adjacent community having different vegetation, soils, or hydrologic conditions.

If it is not possible to locate one or a few plots in a way that adequately represents the vegetation unit being sampled, then percent cover estimates for each species can be made during a meandering survey of the broader

community. If additional quantification of cover estimates is needed, then the optional procedure for point-intercept sampling along transects (see Appendix B) or other sampling procedures may be used to characterize the vegetation unit. To use either of these sampling methods, soil and hydrologic conditions must be uniform across the sampled area.

Definitions of strata

Vegetation strata within the sampled area or plot are sampled separately when evaluating indicators of hydrophytic vegetation. In this region, the vegetation strata described in the Corps Manual are recommended (see below). Unless otherwise noted, a stratum for sampling purposes is defined as having 5 percent or more total plant cover. If a stratum has less than 5 percent cover during the peak of the growing season, then those species and their cover values should be recorded on the data form but should not be used in the calculations for the dominance test, unless it is the only stratum present.

1. *Tree stratum* – Consists of woody plants 3 in. (7.6 cm) or more in diameter at breast height (DBH), regardless of height.
2. *Sapling/shrub stratum* – Consists of woody plants less than 3 in. DBH and greater than or equal to 3.28 ft (1 m) tall.
3. *Herb stratum* – Consists of all herbaceous (non-woody) plants, including herbaceous vines, regardless of size, and woody plants less than 3.28 ft tall.
4. *Woody vines* – Consists of all woody vines greater than 3.28 ft in height.

Plot and sample sizes

Hydrophytic vegetation determinations under the Corps Manual are based on samples taken in representative locations within each community. Random sampling of the vegetation is not required, except for certain sampling approaches in comprehensive determinations or in rare cases where representative sampling might give misleading results. For routine determinations in fairly uniform vegetation, one or more plots in each community are usually sufficient for an accurate determination. Sampling of a multi-layered community is usually accomplished using a graduated series of plots, one for each stratum, or a number of small plots nested within the largest plot (Figure 2). Nested plots to sample the herb stratum can be helpful in forested areas with highly variable understories or in very diverse communities. Plant abundance data are averaged across the multiple small plots.

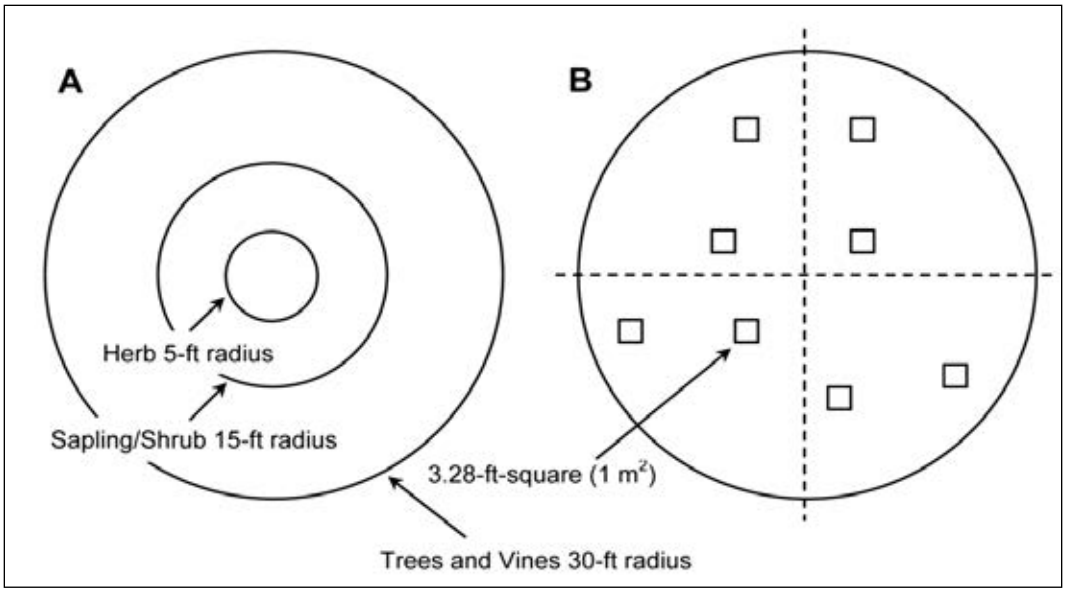


Figure 2. Suggested plot arrangements for vegetation sampling. (A) Single plots in graduated sizes. (B) Nested 3.28- by 3.28-ft square (1-m²) plots for herbs within the 30-ft radius plot.

The appropriate size and shape for a sample plot depend on the type of vegetation (i.e., trees, shrubs, herbaceous plants, etc.) and the size or shape of the plant community or patch being sampled. The size of a plot needs to be large enough to include adequate numbers of individuals in all strata, but small enough so that plant species or individuals can be separated and measured without duplication or omission, and the sampling can be done in a timely fashion (Cox 1990, Barbour et al. 1999). For hydrophytic vegetation determinations, the abundance of each species is determined by using areal cover estimates. Plot sizes should make visual sampling both accurate and efficient. In this region, the following plot sizes are suggested.

1. Tree stratum – 30-ft (9.1-m) radius
2. Sapling/shrub stratum – 15-ft (4.6-m) radius
3. Herb stratum – 5-ft (1.5-m) radius
4. Woody vines – 30-ft (9.1-m) radius

The sampling plot should not be allowed to extend beyond the edges of the plant community being sampled or to overlap an adjacent community having different vegetation, soil, or hydrologic conditions. This may happen if vegetation patches are small or occur as narrow bands or zones along a topographic gradient. In such cases, plot sizes and shapes should be adjusted to fit completely within the vegetation patch or zone. For example, in linear riparian communities where the width of a standard

plot may exceed the width of the plant community, an elongated rectangular plot or belt transect that follows the stream is recommended. If possible, the area sampled should be equivalent to the 30-ft-radius plot (2,827 ft^2 [263 m^2]) for the tree stratum or the 15-ft-radius plot (707 ft^2 [65.7 m^2]) for the sapling/shrub stratum. Thus the sapling/shrub stratum could be sampled using a 10- by 71-ft (3.1- by 21.6-m) plot lying completely within the riparian fringe. An alternative approach involves sampling a series of small subplots (e.g., 5 by 5 ft [1.5 by 1.5 m], or 10 by 10 ft [3.1 by 3.1 m]) in the riparian community and averaging the data across subplots.

A 30-ft radius tree plot works well in most forests but can be increased to 35 ft (10.7 m) or 40 ft (12.2 m) or more in a nonlinear forest stand if tree diversity is high or diameters are large. Highly diverse or patchy communities of herbs or other low vegetation may be sampled with nested 3.28- by 3.28-ft (1-m^2) quadrats randomly located within a 30-ft radius (Figure 2B). Furthermore, point-intercept sampling performed along a transect is an alternative to plot-based methods that can improve the accuracy and repeatability of vegetation sampling in diverse or heterogeneous communities (see Appendix B). To use this method, soil and hydrologic conditions must be uniform across the area where transects are located.

Vegetation sampling guidance presented here should be adequate for hydrophytic vegetation determinations in most situations. However, many variations in vegetation structure, diversity, and spatial arrangement exist on the landscape that are not addressed in this supplement. A list of references is given in Table 2 for more complex sampling situations. If alternative sampling techniques are used, they should be derived from the scientific literature and described in field notes or in the delineation report. The basic data must include abundance values for each species present. Typical abundance measures include basal area for tree species, percent areal cover, stem density, or frequency based on point-intercept sampling. In any case, the data must be in a format that can be used in the dominance test or prevalence index for hydrophytic vegetation (see the section on Hydrophytic Vegetation Indicators).

In this supplement, absolute percent cover is the preferred abundance measure for all species. For percent cover estimates, plants do not need to be rooted in the plot as long as they are growing under the same soil and hydrologic conditions. It may be necessary to exclude plants that overhang the plot if they are rooted in areas having different soil and hydrologic conditions, particularly when sampling near the wetland boundary.

Table 2. Selected references to additional vegetation sampling approaches that could be used in wetland delineation.

Reference	Comment
Brohman, R. J., and L. D. Bryant, eds. 2005. *Existing vegetation classification and mapping technical guide, Version 1.0.* General Technical Report WO-67. Washington, DC: U.S. Department of Agriculture Forest Service.	Contains a brief summary of vegetation sampling methods.
Kent, M., and P. Coker. 1992. *Vegetation description and analysis: A practical approach.* New York, NY: Wiley.	Contains simple and clear methods for setting up a study and collecting and analyzing the data. Initial chapters are helpful for data collection and sampling approaches in wetland delineation.
Mueller-Dombois, D., and H. Ellenberg. 1974. *Aims and methods of vegetation ecology*. New York, NY: Wiley.	A standard text in vegetation ecology, sampling, and analysis. This reference provides many sampling and analytical methods that are helpful in complex delineations.
Tiner, R. W. 1999. *Wetland indicators: A guide to wetland delineation, classification, and mapping.* Boca Raton, FL: CRC Press.	Includes reviews of various sampling techniques and provides a list of vegetation references.
U.S. Department of the Interior (USDI), Bureau of Land Management. 1996. *Sampling vegetation attributes.* BLM/RS/ST-96/002+1730. Denver, CO.	Describes many aspects of vegetation sampling, including sampling protocols, data collection, and analysis.

Basal area is an alternative abundance measure for species in the tree stratum. Basal area of each species in a stand can be estimated quickly and efficiently with a basal-area prism or angle gauge. In this region, a prism with a basal-area factor (BAF) of 10 works well. Basal-area estimates can be used to select dominant species from the tree stratum for use in the dominance test for hydrophytic vegetation (see Hydrophytic Vegetation Indicators). However, basal-area estimates cannot be used to calculate a prevalence index, which is based on absolute percent cover of species in each stratum. Therefore, if basal-area estimates are used initially to evaluate the tree stratum but the dominance test is inconclusive, then the use of the prevalence index will require that the tree stratum be resampled to estimate absolute percent cover of each species.

Seasonal considerations and cautions

To the extent possible, the hydrophytic vegetation decision should be based on the plant community that is normally present during the wet portion of the growing season in a normal rainfall year. However, wetland determinations must often be performed at other times of year, or in years with unusual or atypical weather conditions. The Northcentral and Northeast Region has a temperate climate with cold, snowy winters. Vegetation

sampling for a wetland determination can be challenging when some plants are covered by snow or die back due to freezing temperatures or other factors. At these times, experience and professional judgment may be required to adapt the vegetation sampling scheme or use other sources of information to determine the plant community that is normally present.

When an on-site evaluation of the vegetation is impractical due to snow and ice or other factors, one option is to use existing off-site data sources, such as National Wetlands Inventory (NWI) maps, soil surveys, and aerial photographs, to make a preliminary hydrophytic vegetation determination. These sources may be supplemented with limited on-site data, including those plant species that can be observed and identified. Later, when conditions are favorable, an on-site investigation should be made to verify the preliminary determination and complete the wetland delineation.

Other factors can alter the plant community on a site and affect a hydrophytic vegetation determination, including seasonal changes in species composition, intensive grazing, wildfires and other natural disturbances, and human land-use practices. These factors are considered in Chapter 5.

Hydrophytic vegetation indicators

The following indicators should be applied in the sequence presented. The stepwise procedure is designed to reduce field effort by requiring that only one or two indicators — variations of the dominance test — be evaluated in the majority of wetland determinations. However, hydrophytic vegetation is present if any of the indicators is satisfied. All of these indicators are applicable throughout the entire Northcentral and Northeast Region.

Indicators of hydrophytic vegetation involve looking up the wetland indicator status of plant species on the wetland plant list (Reed [1988] or current list). For the purposes of this supplement, only the five basic levels of wetland indicator status (i.e., OBL, FACW, FAC, FACU, and UPL) are used in hydrophytic vegetation indicators. Plus (+) and minus (–) modifiers are not used (e.g., FAC–, FAC, and FAC+ plants are all considered to be FAC). For species listed as NI (reviewed but given no regional indicator) or NO (no known occurrence in the region at the time the list was compiled), apply the indicator status assigned to the species in the nearest adjacent region. If the species is listed as NI or NO but no adjacent regional indicator is assigned, do not use the species to calculate hydrophytic vegetation

indicators. In general, species that are not listed on the wetland plant list are assumed to be upland (UPL) species. However, recent changes in plant nomenclature have resulted in a number of species that are not listed by Reed (1988) but are not necessarily UPL plants. Procedures described in Chapter 5, in the section on Problematic Hydrophytic Vegetation, can be used if it is believed that individual FACU, NI, NO, or unlisted plant species are functioning as hydrophytes on a particular site. For Clean Water Act purposes, wetland delineators should use the latest plant lists approved by Headquarters, U.S. Army Corps of Engineers (Figure 3) (http://www.usace.army.mil/CECW/Pages/reg_supp.aspx).

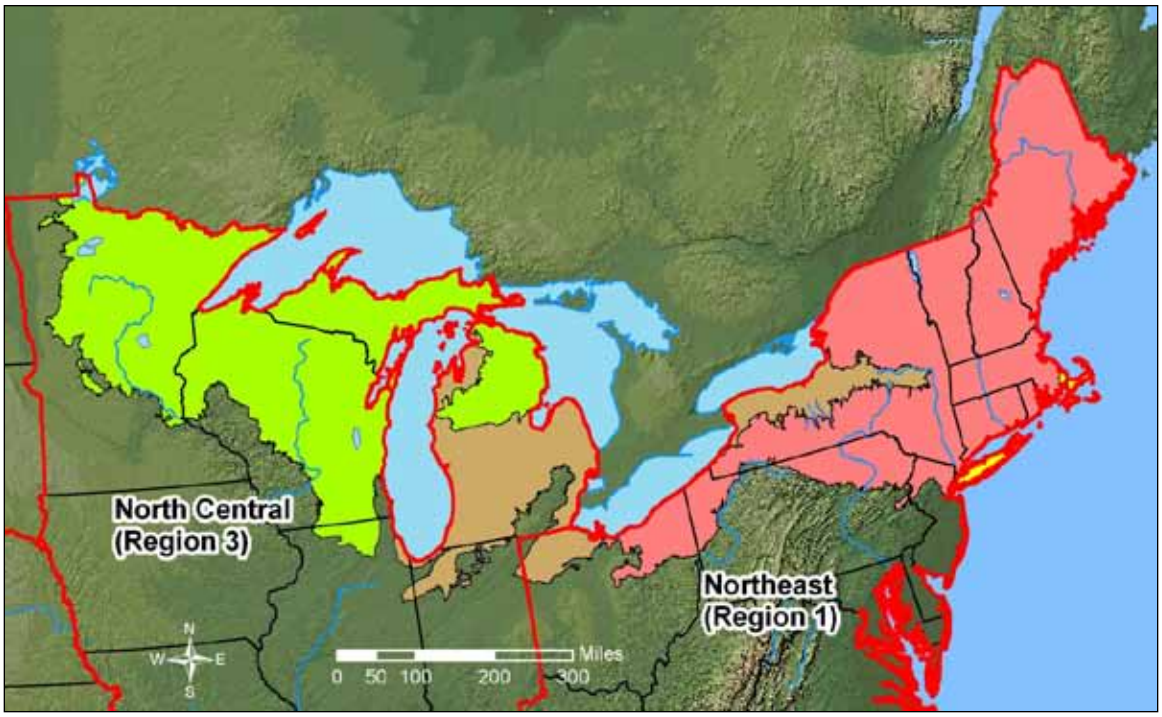


Figure 3. Plant list regional boundaries (red lines) currently used by the U.S. Fish and Wildlife Service, National Wetlands Inventory, in the Northcentral and Northeast Region.

Evaluation of vegetation can begin with a rapid field test for hydrophytic vegetation to determine if there is a need to collect more detailed vegetation data. The rapid test for hydrophytic vegetation (Indicator 1) is met if all dominant species across all strata are OBL or FACW, or a combination of the two, based on a visual assessment. If the site is not dominated solely by OBL and FACW species, proceed to the standard dominance test (Indicator 2), which is the basic hydrophytic vegetation indicator. Either Indicator 1 or 2 should be applied in every wetland determination. Most wetlands in the Northcentral and Northeast Region have plant communities that will meet one or both of these indicators. These are the only indicators that need to be

considered in most situations. However, some wetland plant communities may fail a test based only on dominant species. Therefore, in those cases where indicators of hydric soil and wetland hydrology are present, the vegetation should be re-evaluated with the prevalence index (Indicator 3), which takes non-dominant plant species into consideration, or by observing plant morphological adaptations for life in wetlands (Indicator 4). Finally, certain disturbed or problematic wetland situations may lack any of these indicators and are described in Chapter 5.

Procedure

The procedure for using hydrophytic vegetation indicators is as follows:

1. Apply Indicator 1 (Rapid Test for Hydrophytic Vegetation).
   a. If the plant community passes the rapid test for hydrophytic vegetation, then the vegetation is hydrophytic and no further vegetation analysis is required.
   b. If the rapid test for hydrophytic vegetation is not met, then proceed to step 2.

2. Apply Indicator 2 (Dominance Test).
   a. If the plant community passes the dominance test, then the vegetation is hydrophytic and no further vegetation analysis is required.
   b. If the plant community fails the dominance test, and indicators of hydric soil and/or wetland hydrology are absent, then hydrophytic vegetation is absent unless the site meets requirements for a problematic wetland situation (see Chapter 5).
   c. If the plant community fails the dominance test, but indicators of hydric soil and wetland hydrology are both present, proceed to step 3.

3. Apply Indicator 3 (Prevalence Index). This and the following step assume that at least one indicator of hydric soil and one primary or two secondary indicators of wetland hydrology are present.
   a. If the plant community satisfies the prevalence index, then the vegetation is hydrophytic. No further vegetation analysis is required.
   b. If the plant community fails the prevalence index, proceed to step 4.

4. Apply Indicator 4 (Morphological Adaptations).
   a. If the indicator is satisfied, the vegetation is hydrophytic.
   b. If none of the indicators is satisfied, then hydrophytic vegetation is absent unless indicators of hydric soil and wetland hydrology are

present and the site meets the requirements for a problematic wetland situation (Chapter 5).

Indicator 1: Rapid test for hydrophytic vegetation

Description: All dominant species across all strata are rated OBL or FACW, or a combination of these two categories, based on a visual assessment.

User Notes: This test is intended as a quick confirmation in obvious cases that a site has hydrophytic vegetation, without the need for more intensive sampling. Dominant species are selected visually from each stratum of the community using the "50/20 rule" (see Indicator 2 – Dominance Test below) as a general guide but without the need to gather quantitative data. Only the dominant species in each stratum must be recorded on the data form.

Indicator 2: Dominance test

Description: More than 50 percent of the dominant plant species across all strata are rated OBL, FACW, or FAC.

User Notes: Use the 50/20 rule described below to select dominant species from each stratum of the community. Combine dominant species across strata and apply the dominance test to the combined list. Once a species is selected as a dominant, its cover value is not used in the dominance test; each dominant species is treated equally. Thus, a plant community with seven dominant species across all strata would need at least four dominant species that are OBL, FACW, or FAC to be considered hydrophytic by this indicator. Species that are dominant in two or more strata should be counted in each stratum where they are dominant.

Procedure for Selecting Dominant Species by the 50/20 Rule: Dominant plant species are the most abundant species in the community; they contribute more to the character of the community than do the other non-dominant species present. The 50/20 rule is a repeatable and objective procedure for selecting dominant plant species and is recommended when data are available for all species in the community. The rule can also be used to guide visual sampling of plant communities in rapid wetland determinations.

Dominant species are chosen independently from each stratum of the community. In general, dominants are the most abundant species that individually or collectively account for more than 50 percent of the total coverage of vegetation in the stratum, plus any other species that, by itself, accounts for at least 20 percent of the total. For the purposes of this regional supplement, absolute percent cover is the recommended abundance measure for plants in all vegetation strata. See Table 3 for an example application of the 50/20 rule in evaluating a plant community. Steps in selecting dominant species by the 50/20 rule are as follows:

1. Estimate the absolute percent cover of each species in the first stratum. Since the same data may be used later to calculate the prevalence index, the data should be recorded as absolute cover and not converted to relative cover.
2. Rank all species in the stratum from most to least abundant.
3. Calculate the total coverage of all species in the stratum (i.e., sum their individual percent cover values). Absolute cover estimates do not necessarily sum to 100 percent.
4. Calculate the 50-percent threshold for the stratum by multiplying the total cover of that stratum by 50 percent.
5. Calculate the 20-percent threshold for the stratum by multiplying the total cover of that stratum by 20 percent.
6. Select plant species from the ranked list, in decreasing order of coverage, until the cumulative coverage of selected species *exceeds* the threshold representing 50 percent of the total coverage for the stratum. If two or more species are equal in coverage (i.e., they are tied in rank), they should all be selected. The selected plant species are all considered to be dominants. All dominants must be identified to species.
7. In addition, select any other species that, by itself, is at least 20 percent of the total percent cover in the stratum. Any such species is also considered to be a dominant and must be accurately identified.
8. Repeat steps 1-7 for any other stratum present. Combine the lists of dominant species across all strata. Note that a species may be dominant in more than one stratum (e.g., a woody species may be dominant in both the tree and sapling/shrub strata). Species that are dominant in two or more strata should be counted in each stratum where they are dominant.

Table 3. Example of the selection of dominant species by the 50/20 rule and determination of hydrophytic vegetation by the dominance test.

Stratum	Species Name	Wetland Indicator Status (Region 1)	Absolute Percent Cover	Dominant?
Herb	*Impatiens capensis*	FACW	15	Yes
	Geranium carolinianum	UPL	7	Yes
	Toxicodendron radicans	FAC	5	No
	Lonicera tatarica	FACU	2	No
	Glyceria striata	OBL	2	No
	Parthenocissus quinquefolia	FACU	1	No
	Arisaema triphyllum	FACW	0.5	No
	Carex laxiflora	FACU	0.5	No
		Total cover	33.0	
		50/20 Thresholds: 50% of total cover = 16.5% 20% of total cover = 6.6%		
Sapling/shrub	*Carpinus caroliniana*	FAC	35	Yes
	Carya ovata	FACU	10	No
	Acer saccharum	FACU	5	No
	Quercus rubra	FACU	5	No
		Total cover	55.0	
		50/20 Thresholds: 50% of total cover = 27.5% 20% of total cover = 11.0%		
Tree	*Quercus bicolor*	FACW	40	Yes
	Fraxinus pennsylvanica	FACW	17	Yes
	Ulmus americana	FACW	10	No
	Carya ovata	FACU	8	No
		Total Cover	75.0	
		50/20 Thresholds: 50% of total cover = 37.5% 20% of total cover = 15.0%		
Woody vine	*Toxicodendron radicans*	FAC	1	No[1]
Hydrophytic Vegetation Determination	Total number of dominant species across all strata = 5. Percent of dominant species that are OBL, FACW, or FAC = 80%. Therefore, this community is hydrophytic by Indicator 2 (Dominance Test).			

[1] A stratum with less than 5 percent total cover is not considered in the dominance test, unless it is the only stratum present.

Indicator 3: Prevalence index

Description: The prevalence index is 3.0 or less.

User Notes: The prevalence index ranges from one to five. A prevalence index of 3.0 or less indicates that hydrophytic vegetation is present. If

practical, all species in the plot should be identified and recorded on the data form. At a minimum, at least 80 percent of the total vegetation cover on the plot (summed across all strata) must be of species that have been correctly identified and have assigned wetland indicator statuses (Reed [1988] or current list) or are not listed and assumed to be UPL.

Procedure for Calculating a Plot-Based Prevalence Index: The prevalence index is a weighted-average wetland indicator status of all plant species in the sampling plot. All plants are given a numeric value based on indicator status (OBL = 1, FACW = 2, FAC = 3, FACU = 4, and UPL = 5) and their abundance (absolute percent cover) is used to calculate the prevalence index. It is a more comprehensive analysis of the hydrophytic status of the community than one based on just a few dominant species. It is particularly useful in (1) communities with only one or two dominants, (2) highly diverse communities where many species may be present at roughly equal coverage, and (3) cases where strata differ greatly in total plant cover (e.g., total herb cover is 80 percent but sapling/shrub cover is only 10 percent).

The following procedure is used to calculate a plot-based prevalence index. The method was described by Wentworth et al. (1988) and modified by Wakeley and Lichvar (1997). It uses the same field data (i.e., percent cover estimates for each plant species) that were used to select dominant species by the 50/20 rule, with the added constraint that at least 80 percent of the total vegetation cover on the plot must be of species that have been correctly identified and have an assigned indicator status (including UPL). For any species that occurs in more than one stratum, cover estimates are summed across strata. Steps for determining the prevalence index are as follows:

1. Identify and estimate the absolute percent cover of each species in each stratum of the community. Sum the cover estimates for any species that is present in more than one stratum.
2. Organize all species (across all strata) into groups according to their wetland indicator status (i.e., OBL, FACW, FAC, FACU, or UPL) and sum their cover values within groups. Do not include species that were not identified.
3. Calculate the prevalence index using the following formula:

$$PI = \frac{A_{OBL} + 2A_{FACW} + 3A_{FAC} + 4A_{FACU} + 5A_{UPL}}{A_{OBL} + A_{FACW} + A_{FAC} + A_{FACU} + A_{UPL}}$$

where:

PI = Prevalence index
A_{OBL} = Summed percent cover values of obligate (OBL) plant species;
A_{FACW} = Summed percent cover values of facultative wetland (FACW) plant species;
A_{FAC} = Summed percent cover values of facultative (FAC) plant species;
A_{FACU} = Summed percent cover values of facultative upland (FACU) plant species;
A_{UPL} = Summed percent cover values of upland (UPL) plant species.

See Table 4 for an example calculation of the prevalence index using the same data set as in Table 3. The following web link provides free public-domain software for simultaneous calculation of the 50/20 rule, dominance test, and prevalence index: http://www.crrel.usace.army.mil/rsgisc/wetshed/wetdatashed.htm.

Table 4. Example of the Prevalence Index using the same data as in Table 3.

Indicator Status Group	Species Name	Absolute Percent Cover by Species	Total Cover by Group	Multiply by:[1]	Product
OBL species	*Glyceria striata*	2	2	1	2
FACW species	*Impatiens capensis*	15	82.5	2	165
	Arisaema triphyllum	0.5			
	Quercus bicolor	40			
	Fraxinus pennsylvanica	17			
	Ulmus americana	10			
FAC species	*Toxicodendron radicans*[2]	6	41	3	123
	Carpinus caroliniana	35			
FACU species	*Lonicera tatarica*	2	31.5	4	126
	Parthenocissus quinquefolia	1			
	Carex laxiflora	0.5			
	Carya ovata[3]	18			
	Acer saccharum	5			
	Quercus rubra	5			
UPL species	*Geranium carolinianum*	7	7	5	35
Sum			164 (A)		451 (B)
Hydrophytic Vegetation Determination		Prevalence Index = B/A = 451/164 = 2.75 Therefore, this community is hydrophytic by Indicator 3 (Prevalence Index).			

[1] Where OBL = 1, FACW = 2, FAC = 3, FACU = 4, and UPL = 5.

[2] A stratum with less than 5 percent cover is not considered in the dominance test but is included in the prevalence index. *Toxicodendron radicans* was recorded in two strata (see Table 3), so the cover estimates for this species were summed across strata.

[3] *Carya ovata* was recorded in two strata (see Table 3) so the cover estimates for this species were summed across strata.

Indicator 4: Morphological adaptations

Description: The plant community passes either the dominance test (Indicator 2) or the prevalence index (Indicator 3) after reconsideration of the indicator status of certain plant species that exhibit morphological adaptations for life in wetlands.

User Notes: Some hydrophytes in the Northcentral and Northeast Region develop easily recognized physical characteristics, or morphological adaptations, when they occur in wetland areas. Some of these adaptations may help them to survive prolonged inundation or saturation in the root zone; others may simply be a consequence of living under such wet conditions. Common morphological adaptations in the region include, but are not limited to, adventitious roots, hypertrophied lenticels, multi-stemmed trunks, and shallow root systems developed on or near the soil surface (Figure 4). Users need to be cautious that shallow roots were not caused by erosion, near-surface bedrock, or rocky till, and that multi-trunk plants were not the result of sprouting after logging or browsing. Morphological adaptations may develop on FACU species when they occur in wetlands, indicating that those individuals are functioning as hydrophytes in that setting.

To apply this indicator, these morphological features must be observed on more than 50 percent of the individuals of a FACU species living in an area where indicators of hydric soil and wetland hydrology are present. Follow this procedure:

1. Confirm that the morphological feature is present mainly in the potential wetland area and is not also common on the same species in the surrounding non-wetlands.
2. For each FACU species that exhibits morphological adaptations, estimate the percentage of individuals that have the features. Record this percentage on the data form.
3. If more than 50 percent of the individuals of a FACU species have morphological adaptations for life in wetlands, that species is considered to be a hydrophyte and its indicator status on that plot should be reassigned as FAC. All other species retain their published indicator statuses. Record any supporting information on the data sheet, including a description of the morphological adaptation(s) present and any other observations of the growth habit of the species in adjacent wetland and non-wetland locations (photo documentation is recommended).

4. Recalculate the dominance test (Indicator 2) and/or the prevalence index (Indicator 3) using a FAC indicator status for this species. The vegetation is hydrophytic if either test is satisfied.



Figure 4. Shallow roots of eastern hemlock are a response to high water tables in this forested wetland.

3 Hydric Soil Indicators

Introduction

The National Technical Committee for Hydric Soils (NTCHS) defines a hydric soil as a soil that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part (USDA Soil Conservation Service 1994). Most hydric soils exhibit characteristic morphologies that result from repeated periods of saturation or inundation for more than a few days. Saturation or inundation, when combined with microbial activity in the soil, causes the depletion of oxygen. This anaerobiosis promotes certain biogeochemical processes, such as the accumulation of organic matter and the reduction, translocation, or accumulation of iron and other reducible elements. These processes result in distinctive characteristics that persist in the soil during both wet and dry periods, making them particularly useful for identifying hydric soils in the field (USDA Natural Resources Conservation Service 2010).

This chapter presents indicators that are designed to help identify hydric soils in the Northcentral and Northeast Region. Indicators are not intended to replace or relieve the requirements contained in the definition of a hydric soil. Therefore, a soil that meets the definition of a hydric soil is hydric whether or not it exhibits indicators. Guidance for identifying hydric soils that lack indicators can be found later in this chapter (see the sections on documenting the site and its soils) and in Chapter 5 (Difficult Wetland Situations in the Northcentral and Northeast Region).

This list of indicators is dynamic; changes and additions to the list are anticipated with new research and field testing. The indicators presented in this supplement are a subset of the NTCHS *Field Indicators of Hydric Soils in the United States* (USDA Natural Resources Conservation Service [2010 or current version) that are commonly found in the region. Any change to the NTCHS *Field Indicators of Hydric Soils in the United States* represents a change to this subset of indicators for the Northcentral and Northeast Region. The current version of the indicators can be found on the NRCS hydric soils web site (http://soils.usda.gov/use/hydric). To use the indicators properly, a basic knowledge of soil/landscape relationships is necessary.

Most of the hydric soil indicators presented in this Supplement are applicable throughout the region; however, some are specific to certain subregions. As used in this supplement, subregions are equivalent to the Land Resource Regions (LRR) or Major Land Resource Areas (MLRA) recognized by the USDA Natural Resources Conservation Service (2006) (see Chapter 1, Figure 1). It is important to understand that boundaries between subregions are actually broad transition zones. Although an indicator may be noted as most relevant in a specific subregion, it may also be applicable in the transition to an adjacent subregion.

Concepts

Hydric soil indicators are formed predominantly by the accumulation or loss of iron, manganese, sulfur, or carbon compounds in a saturated and anaerobic environment. These processes and the features that develop are described in the following paragraphs.

Iron and manganese reduction, translocation, and accumulation

In an anaerobic environment, soil microbes reduce iron from the ferric (Fe^{3+}) to the ferrous (Fe^{2+}) form, and manganese from the manganic (Mn^{4+}) to the manganous (Mn^{2+}) form. Of the two, evidence of iron reduction is more commonly observed in soils. Areas in the soil where iron is reduced often develop characteristic bluish-gray or greenish-gray colors known as *gley*. Ferric iron is insoluble but ferrous iron easily enters the soil solution and may be moved or translocated to other areas of the soil. Areas that have lost iron typically develop characteristic gray or reddish-gray colors and are known as *redox depletions*. If a soil reverts to an aerobic state, iron that is in solution will oxidize and become concentrated in patches and along root channels and other pores. These areas of oxidized iron are called *redox concentrations*. Since water movement in these saturated or inundated soils can be multi-directional, redox depletions and concentrations can occur anywhere in the soil and have irregular shapes and sizes. Soils that are saturated and contain ferrous iron at the time of sampling may change color upon exposure to the air, as ferrous iron is rapidly converted to ferric iron in the presence of oxygen. Such soils are said to have a *reduced matrix* (Vepraskas 1992).

While indicators related to iron or manganese depletion or concentration are the most common in hydric soils, they cannot form in soils whose parent materials are low in Fe or Mn. Soils formed in such materials may

have low-chroma colors that are not related to saturation and reduction. For such soils, features formed through accumulation of organic carbon may be present.

Sulfate reduction

Sulfur is one of the last elements to be reduced by microbes in an anaerobic environment. The microbes convert SO_4^{2-} to H_2S, or hydrogen sulfide gas. This results in a very pronounced "rotten egg" odor in some soils that are inundated or saturated for very long periods. In non-saturated or non-inundated soils, sulfate is not reduced and there is no rotten egg odor. The presence of hydrogen sulfide is a strong indicator of a hydric soil, but this indicator is found only in the wettest sites in soils that contain sulfur-bearing compounds.

Organic matter accumulation

Soil microbes use carbon compounds found in organic matter as an energy source. However, the rate at which organic carbon is utilized by soil microbes is considerably lower in a saturated and anaerobic environment than under aerobic conditions. Therefore, in saturated soils, partially decomposed organic matter may accumulate. The result in wetlands is often the development of thick organic surfaces, such as peat or muck, or dark organic-rich mineral surface layers.

Non-saturated or non-inundated organic soils. In northern regions, cool temperatures and acid conditions slow the decomposition of organic matter. Under these conditions, even some well-drained soils, under predominantly aerobic conditions, can develop thick organic surface layers called folistic epipedons. These layers are not necessarily related to wetness. Folistic layers are organic accumulations that are saturated less than 30 days cumulatively in normal years (USDA Natural Resources Conservation Service 1999). Most folistic layers consist of poorly decomposed organic material (i.e., fibric or hemic material; see the following section) although some consist of highly decomposed (i.e., sapric) material. Folistic surface layers may overlie rock, a mineral layer, or saturated organic layers, and are most commonly found on north- and east-facing slopes, in dense shade, and on nearly level, convex landforms in coniferous or mixed deciduous/coniferous forests in the colder, northern or high-elevation portions of the region. It may be necessary to involve a soil

scientist with local knowledge to help distinguish folistic surface layers from saturated organic layers.

Determining the texture of soil materials high in organic carbon. Material high in organic carbon could fall into three categories: organic, mucky mineral, or mineral. In lieu of laboratory data, the following estimation method can be used for soil material that is wet or nearly saturated with water. This method may be inconclusive with loamy or clayey textured mineral soils. Gently rub the wet soil material between forefinger and thumb. If upon the first or second rub the material feels gritty, it is mineral soil material. If after the second rub the material feels greasy, it is either mucky mineral or organic soil material. Gently rub the material two or three more times. If after these additional rubs it feels gritty or plastic, it is mucky mineral soil material; if it still feels greasy, it is organic soil material. If the material is organic soil material a further division should be made, as follows.

Organic soil materials are classified as sapric, hemic, or fibric based on the percentage of visible fibers observable with a hand lens in an undisturbed state and after rubbing between thumb and fingers 10 times (Table 5). If there is a conflict between unrubbed and rubbed fiber content, rubbed content is used. *Live roots are not considered*. In saturated organic materials, the terms sapric, hemic, and fibric correspond to the textures muck, mucky peat, and peat, respectively (Table 5). The terms muck, mucky peat, and peat should only be used for organic accumulations associated with wetness.

Table 5. Proportion of sample consisting of fibers visible with a hand lens.

Unrubbed	Rubbed	Horizon Descriptor	Soil Texture (Saturated Organic Soils)
<33%	<17%	Sapric	Muck
33-67%	17-40%	Hemic	Mucky peat
>67%	>40%	Fibric	Peat

Adapted from USDA Natural Resources Conservation Service (1999).

Another field method for determining the degree of decomposition for organic materials is a system modified from a method originally developed by L. von Post and described in detail in ASTM standard D 5715-00 (http://www.astm.org/). This method is based on a visual examination of the color of the water that is expelled and the soil material remaining in the

hand after a saturated sample is squeezed (Table 6). If a conflict occurs between results for sapric, hemic, or fibric material using percent visible fiber (Table 5) and degree of humification (Table 6), then percent visible fiber should be used.

Table 6. Determination of degree of decomposition of organic materials.

Degree of Humification	Nature of Material Extruded upon Squeezing	Nature of Plant Structure in Residue	Horizon Descriptor	Soil Texture
H1	Clear, colorless water; no organic solids squeezed out	Unaltered, fibrous, undecomposed	Fibric	Peat
H2	Yellowish water; no organic solids squeezed out	Almost unaltered, fibrous		
H3	Brown, turbid water; no organic solids squeezed out	Easily identifiable		
H4	Dark brown, turbid water; no organic solids squeezed out	Visibly altered but identifiable	Hemic	Mucky Peat
H5	Turbid water and some organic solids squeezed out	Recognizable but vague, difficult to identify		
H6	Turbid water; 1/3 of sample squeezed out	Indistinct, pasty		
H7	Very turbid water; 1/2 of sample squeezed out	Faintly recognizable; few remains identifiable, mostly amorphous	Sapric	Muck
H8	Thick and pasty; 2/3 of sample squeezed out	Very indistinct		
H9	No free water; nearly all of sample squeezed out	No identifiable remains		
H10	No free water; all of sample squeezed out	Completely amorphous		

Cautions

A soil that is artificially drained or protected (for instance, by dikes or levees) is still hydric if the soil in its undisturbed state would meet the definition of a hydric soil. To be identified as hydric, these soils should generally have one or more of the indicators. However, not all areas that have hydric soils will qualify as wetlands if they no longer have wetland hydrology or do not support hydrophytic vegetation.

Morphological features that do not reflect contemporary or recent conditions of saturation and anaerobiosis are called relict features. Contemporary and relict hydric soil features can be difficult to distinguish. For example,

nodules and concretions that are actively forming often have gradual or diffuse boundaries, whereas relict or degrading nodules and concretions have sharp boundaries (Vepraskas 1992). Guidance for some of the most common problem hydric soils can be found in Chapter 5. When soil morphology seems inconsistent with the landscape, vegetation, or observable hydrology, it may be necessary to obtain the assistance of an experienced soil or wetland scientist to determine whether the soil is hydric.

Procedures for sampling soils

Observe and document the site

Before making any decision about the presence or absence of hydric soils, the overall site and how it interacts with the soil should be considered. The questions below, while not required to identify a hydric soil, can help to explain why a hydric soil is or is not present. Always look at the landscape features of the immediate site and compare them to the surrounding areas. Try to contrast the features of wet and dry sites that are in close proximity. When observing slope features, look first at the area immediately around the sampling point. For example, a nearly level bench or depression at the sampling point may be more important to site wetness than the overall landform on which it occurs. By understanding how water moves across the site, the reasons for the presence or absence of hydric soil indicators should be clear.

If one or more of the hydric soil indicators given later in this chapter is present, then the soil is hydric. If no hydric soil indicator is present, the additional site information below may be useful in documenting whether the soil is indeed non-hydric or if it might represent a “problem” hydric soil that meets the hydric soil definition despite the absence of indicators.

- *Hydrology*–Is standing water observed on the site or is water observed in the soil pit? What is the depth of the water table in the area? Is there indirect evidence of ponding or flooding?
- *Slope*–Is the site level or nearly level so that surface water does not run off readily, or is it steeper where surface water would run off from the soil?
- *Slope shape*–Is the surface concave (e.g., depressions), where water would tend to collect and possibly pond on the soil surface? On hillsides, are there convergent slopes (Figure 5), where surface or

groundwater may be directed toward a central stream or swale? Is the surface or slope shape convex, causing water to run off or disperse?

- *Landform*–Is the soil on a low terrace or floodplain that may be subject to seasonal high water tables or flooding? Is it at the toe of a slope (Figure 6) where runoff may tend to collect or groundwater emerge at or near the surface? Has the microtopography been altered by cultivation?
- *Soil materials*–Is there a restrictive layer in the soil that could slow or prevent the infiltration of water, perhaps resulting in a perched water table? Restrictive layers could include consolidated bedrock, fragipans, dense glacial till, layers of silt or substantial clay content, strongly contrasting soil textures (e.g., silt over sand), or cemented layers, such as ortstein. Or is there relatively loose soil material (sand, gravel, or rocks) or fractured bedrock that would allow the water to flow laterally down slope?
- *Vegetation*–Does the vegetation at the site indicate wetter conditions than at other nearby sites, or is it similar to what is found at nearby upland sites?

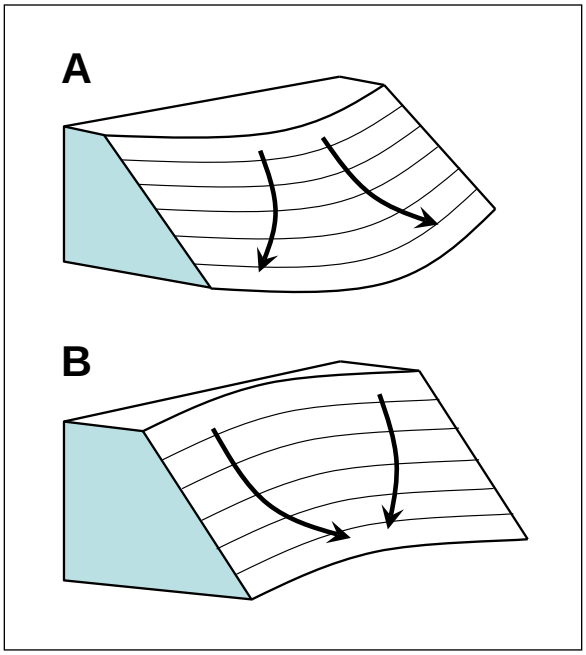


Figure 5. Divergent slopes (A) disperse surface water, whereas convergent slopes (B) concentrate water. Surface flow paths are indicated by the arrows.

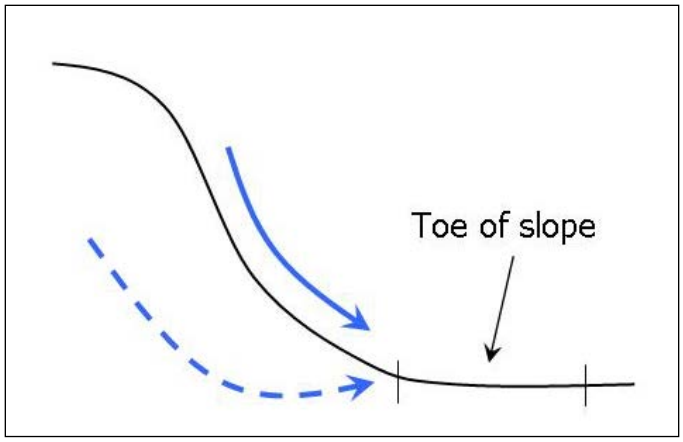


Figure 6. At the toe of a hill slope, the gradient is only slightly inclined or nearly level. Blue arrows represent flow paths of surface water (solid arrow) and groundwater (dashed arrow).

Observe and document the soil

To observe and document a hydric soil, first remove any loose leaves, needles, or bark from the soil surface. Do not remove the organic surface layers of the soil, which usually consist of plant remains in varying stages of decomposition. Dig a hole and describe the soil profile. In general, the hole should be dug to the depth needed to document an indicator or to confirm the absence of indicators. For most soils, the recommended excavation depth is approximately 20 in. (50 cm) from the soil surface, although a shallower soil pit may suffice for some indicators (e.g., A2 – Histic Epipedon). Digging may be difficult in some areas due to rocks and hardpans. Use the completed profile description to determine which hydric soil indicators have been met (USDA Natural Resources Conservation Service 2010).

For soils with deep, dark surface layers, deeper examination may be required when field indicators are not easily seen within 20 in. (50 cm) of the surface. The accumulation of organic matter in these soils may mask redoximorphic features in the surface layers. Examination to 40 in. (1 m) or more may be needed to determine whether they meet the requirements of indicator A12 (Thick Dark Surface). A soil auger or probe may be useful for sampling soil materials below 20 in.

Whenever possible, excavate the soil deep enough to determine if there are layers or materials present that might restrict soil drainage. This will help to understand why the soil may or may not be hydric. After a sufficient

number of exploratory excavations have been made to understand the soil-hydrologic relationships at the site, subsequent excavations can be limited to the depth needed to identify hydric soil indicators. Consider taking photographs of both the soil and the overall site, including a clearly marked measurement scale in soil pictures.

The starting point for depth measurements used in the indicators varies by Land Resource Region (LRR). In LRR R (Figure 1), depths are measured from the mineral surface (underneath any and all fibric, hemic, and/or sapric material), except for indicators A1 (Histosol), A2 (Histic Epipedon), A3 (Black Histic), and S3 (Mucky Peat or Peat) for which measurements begin at the actual soil surface. In all other LRRs in the Northcentral and Northeast Region, measurements begin at the muck or mineral surface (underneath any fibric and/or hemic material), except for indicators A1, A2, A3, and S3 where they begin at the actual soil surface (USDA Natural Resources Conservation Service 2010).

All colors noted in this supplement refer to moist Munsell® colors (Gretag/Macbeth 2000). Do not attempt to determine colors while wearing sunglasses or tinted lenses. Colors must be determined under natural light and not under artificial light.

Soil colors specified in the indicators do not have decimal points (except for indicator A12); however, intermediate colors do occur between Munsell chips. Soil color should not be rounded to qualify as meeting an indicator. For example, a soil matrix with a chroma between 2 and 3 should be recorded as having a chroma of 2+. This soil material does not have a chroma of 2 and would not meet any indicator that requires a chroma of 2 or less.

Always examine soil matrix colors in the field immediately after sampling. Ferrous iron, if present, can oxidize rapidly and create colors of higher chroma or redder hue. In soils that are saturated at the time of sampling, redox concentrations may be absent or difficult to see, particularly in dark-colored soils. It may be necessary to let the soil dry to a moist state (5 to 30 minutes or more) for the iron or manganese to oxidize and redox features to become visible.

Particular attention should be paid to changes in microtopography over short distances. Small changes in elevation may result in repetitive

sequences of hydric/non-hydric soils, making the delineation of individual areas of hydric and non-hydric soils difficult. Often the dominant condition (hydric or non-hydric) is the only reliable interpretation (also see the section on Wetland/Non-Wetland Mosaics in Chapter 5). The shape of the local landform can greatly affect the movement of water through the landscape. Significant changes in parent material or lithologic discontinuities in the soil can also affect the hydrologic properties of the soil.

Use of existing soil data

Soil surveys

Soil surveys are available for most areas of the Northcentral and Northeast Region and can provide useful information regarding soil properties and soil moisture conditions for an area. A list of available soil surveys is located at http://soils.usda.gov/survey/online_surveys/, and soil survey maps and data are available online from the Web Soil Survey at http://websoilsurvey.nrcs.usda.gov/. Soil survey maps divide the landscape into areas called map units. Map units usually contain more than one soil type or component. They often contain several minor components or inclusions of soils with properties that may be similar to or quite different from the major component. Some of these inclusions may be hydric while the major component is not, and vice versa. Those soils that are hydric are noted in the *Hydric Soils List* published separately from the soil survey report. Soil survey information can be valuable for planning purposes, but it is not site-specific and does not preclude the need for an on-site investigation.

Hydric soils lists

Hydric Soils Lists are developed for each detailed soil survey. Using criteria approved by the NTCHS, these lists rate each soil component as either hydric or non-hydric based on soil property data. If the soil is rated as hydric, information is provided regarding which hydric criteria are met and on what landform the soil typically occurs. Hydric Soils Lists are useful as general background information for an on-site delineation. The hydric soils list should be used as a tool, indicating that hydric soil will likely be found within a given area. However, not all areas within a polygon identified as having hydric soils may be hydric.

Hydric Soils Lists developed for individual detailed soil surveys are known as Local Hydric Soils Lists. They are available from state or county NRCS

offices and over the internet from the Soil Data Mart (http://soildatamart.nrcs.usda.gov/). Local Hydric Soils Lists have been compiled into a National Hydric Soils List available at http://soils.usda.gov/use/hydric/. However, use of Local Hydric Soils Lists is preferred since they are more current and reflect local variations in soil properties.

Hydric soil indicators

Many of the hydric soil indicators were developed specifically for wetland-delineation purposes. During the development of these indicators, soils in the interior of wetlands were not always examined; therefore, there are wetlands that lack any of the approved hydric soil indicators in the wettest interior portions. Wetland delineators and other users of the hydric soil indicators should concentrate their sampling efforts near the wetland edge and, if these soils are hydric, assume that soils in the wetter, interior portions of the wetland are also hydric, even if they lack an indicator.

Hydric soil indicators are presented in three groups. Indicators for "All Soils" are used in any soil regardless of texture. Indicators for "Sandy Soils" are used in soil layers with USDA textures of loamy fine sand or coarser. Indicators for "Loamy and Clayey Soils" are used with soil layers of loamy very fine sand and finer. Both sandy and loamy/clayey layers may be present in the same soil profile. Therefore, a soil that contains a loamy surface layer over sand is hydric if it meets all of the requirements of matrix color, amount and contrast of redox concentrations, depth, and thickness for a specific A (All Soils), F (Loamy and Clayey Soils), or S (Sandy Soils) indicator. Additional indicators for problematic hydric soils are presented on pages 71-79. These indicators are used in conjunction with the procedure given in Chapter 5.

It is permissible to combine certain hydric soil indicators if all requirements of the individual indicators are met except thickness (see Hydric Soil Technical Note 4, http://soils.usda.gov/use/hydric/ntchs/tech_notes/index.html). The most restrictive requirements for thickness of layers in any indicators used must be met. Not all indicators are possible candidates for combination. For example, indicator F2 (Loamy Gleyed Matrix) has no thickness requirement, so a site would either meet the requirements of this indicator or it would not. Table 7 lists the indicators that are the most likely candidates for combining in the region.

Table 7. Minimum thickness requirements for commonly combined indicators in the Northcentral and Northeast Region.

Indicator	Thickness Requirement
S5 – Sandy Redox	4 in. (10 cm) thick starting within 6 in. (15 cm) of the soil surface
S7 – Dark Surface	4 in. (10 cm) thick starting within 6 in. (15 cm) of the soil surface
F1 – Loamy Mucky Mineral	4 in. (10 cm) thick starting within 6 in. (15 cm) of the soil surface
F3 – Depleted Matrix	6 in. (15 cm) thick starting within 10 in. (25 cm) of the soil surface
F6 – Redox Dark Surface	4 in. (10 cm) thick entirely within the upper 12 in. (30 cm)
F7 – Depleted Dark Surface	4 in. (10 cm) thick entirely within the upper 12 in. (30 cm)

Table 8 presents an example of a soil in which a combination of layers meets the requirements for indicators F6 (Redox Dark Surface) and F3 (Depleted Matrix). The second layer meets the morphological characteristics of F6 and the third layer meets the morphological characteristics of F3, but neither meets the thickness requirement for its respective indicator. However, the combined thickness of the second and third layers meets the more restrictive conditions of thickness for F3 (i.e., 6 in. [15 cm] starting within 10 in. [25 cm] of the soil surface). Therefore, the soil is considered to be hydric based on the combination of indicators.

Table 8. Example of a soil that is hydric based on a combination of indicators F6 and F3.

Depth (inches)	Matrix Color	Redox Concentrations			Texture
		Color	Abundance	Contrast	
0 – 3	10YR 2/1	--	--	--	Loamy/clayey
3 – 6	10YR 3/1	7.5YR 5/6	3 percent	Prominent	Loamy/clayey
6 – 10	10YR 5/2	7.5YR 5/6	5 percent	Prominent	Loamy/clayey
10 – 14	2.5Y 4/2	--	--	--	Loamy/clayey

Another common situation in which it is appropriate to combine the characteristics of hydric soil indicators is when stratified textures of sandy (i.e., loamy fine sand and coarser) and loamy (i.e., loamy very fine sand and finer) material occur in the upper 12 in. of the soil. For example, the soil shown in Table 9 is hydric based on a combination of indicators F6 (Redox Dark Surface) and S5 (Sandy Redox). This soil meets the morphological characteristics of F6 in the first layer and S5 in the second layer, but neither layer by itself meets the thickness requirement for its respective indicator. However, the combined thickness of the two layers (6 in.) meets the more restrictive thickness requirement of either indicator (4 in.).

Table 9. Example of a soil that is hydric based on a combination of indicators F6 and S5.

Depth (inches)	Matrix Color	Redox Concentrations			Texture
		Color	Abundance	Contrast	
0 – 3	10YR 3/1	10YR 5/6	3 percent	Prominent	Loamy/clayey
3 – 6	10YR 4/1	10YR 5/6	3 percent	Prominent	Sandy
6 – 16	10YR 4/1	--	--	--	Loamy/clayey

All soils

"All soils" refers to soils with any USDA soil texture. Use the following indicators regardless of soil texture.

All mineral layers above any of the layers meeting an A indicator, except for indicator A16, must have a dominant chroma of 2 or less, or the layer(s) with a dominant chroma of more than 2 must be less than 6 in. (15 cm) thick to meet any hydric soil indicator. Nodules and concretions are not considered to be redox concentrations unless otherwise noted.

Indicator A1: Histosol

Technical Description: Classifies as a Histosol (except Folists)

Applicable Subregions: Applicable throughout the Northcentral and Northeast Region.

User Notes: In most Histosols, 16 in. (40 cm) or more of the upper 32 in. (80 cm) is organic soil material (Figure 7). Histosols also include soils that have organic soil material of any thickness over rock or fragmental soil material that has interstices filled with organic soil material (Figure 8). Organic soil material has an organic carbon content (by weight) of 12 to 18 percent or more, depending on the clay content of the soil. The material includes muck (sapric soil material), mucky peat (hemic soil material), or peat (fibric soil material). See the glossary of *Field Indicators of Hydric Soils in the United States* (USDA Natural Resources Conservation Service 2010) for definitions of muck, mucky peat, peat, and organic soil material. See the Concepts section of this chapter for field methods to identify organic soil materials, and Appendix A for the definition of fragmental soil material.



Figure 7. Example of a Histosol, in which muck (sapric soil material) is greater than 3 ft (0.9 m) thick.



Figure 8. This Histosol consists of only a few inches of organic soil material over bedrock in a shallow glacial groove.

Histosols are relatively abundant in the Northcentral and Northeast Region. They are often found in bogs, fens, and slope wetlands that are ponded or saturated to the surface nearly all of the growing season in most years. Use caution in areas that may have folistic surface layers (see the Concepts section of this chapter). Folistic layers do not meet the requirements of this indicator.

Indicator A2: Histic Epipedon

Technical Description: A histic epipedon underlain by mineral soil material with a chroma of 2 or less.

Applicable Subregions: Applicable throughout the Northcentral and Northeast Region.

User Notes: Most histic epipedons are surface horizons 8 in. (20 cm) or more thick of organic soil material (Figure 9). Aquic conditions or artificial drainage are required (see *Soil Taxonomy*, USDA Natural Resources Conservation Service 1999); however, aquic conditions can be assumed if indicators of hydrophytic vegetation and wetland hydrology are present. See the glossary of *Field Indicators of Hydric Soils in the United States* (USDA Natural Resources Conservation Service 2010) for definitions. See the Concepts section of this chapter for field methods to identify organic soil materials. See indicator A1 for organic carbon requirements. Slightly lower organic carbon contents are allowed in plowed soils.



Figure 9. In this soil, the organic surface layer is about 9 in. (23 cm) thick. Scale is in centimeters.

This indicator is common in the region. It is often found in bogs, fens, and slope wetlands that are ponded or saturated to the surface nearly all of the growing season in most years.

Indicator A3: Black Histic

Technical Description: A layer of peat, mucky peat, or muck 8 in. (20 cm) or more thick that starts within 6 in. (15 cm) of the soil surface; has a hue of 10YR or yellower, value of 3 or less, and chroma of 1 or less; and is underlain by mineral soil material with a chroma of 2 or less.

Applicable Subregions: Applicable throughout the Northcentral and Northeast Region.

User Notes: This indicator does not require proof of aquic conditions or artificial drainage. See the glossary of *Field Indicators of Hydric Soils in the United States* (USDA Natural Resources Conservation Service 2010) for definitions of peat, mucky peat, and muck. See the Concepts section of this chapter for field methods to identify organic soil materials. See indicator A1 for organic carbon requirements.

This indicator is common in the region. It is often found in bogs, fens, and slope wetlands that are ponded or saturated to the surface nearly all of the growing season in most years.

Indicator A4: Hydrogen Sulfide

Technical Description: A hydrogen sulfide (rotten egg) odor within 12 in. (30 cm) of the soil surface.

Applicable Subregions: Applicable throughout the Northcentral and Northeast Region.

User Notes: Any time the soil smells of hydrogen sulfide (rotten egg odor), sulfur is currently being reduced and the soil is definitely in an anaerobic state. In some soils, the odor is pronounced; in others it is very fleeting as the gas dissipates rapidly. If in doubt, quickly open several small holes in the area of concern to determine if a hydrogen sulfide odor is really present. This indicator generally is not found at the boundaries between wetlands and non-wetlands. It is most commonly found in areas that are permanently saturated or inundated.

Indicator A5: Stratified Layers

Technical Description: Several stratified layers starting within 6 in. (15 cm) of the soil surface. At least one of the layers has a value of 3 or less with a chroma of 1 or less or it is muck, mucky peat, peat, or mucky modified mineral texture. The remaining layers have chromas of 2 or less (Figure 10). Any sandy material that constitutes the layer with a value of 3 or less and a chroma of 1 or less, when viewed with a 10- or 15-power hand lens, must have at least 70 percent of the visible soil particles masked with organic material (Figure 11). When viewed without a hand lens, the material appears to be nearly 100 percent masked.



Figure 10. Stratified layers in loamy material.



Figure 11. Stratified layers in sandy material.

Applicable Subregions: Applicable throughout the Northcentral and Northeast Region.

User Notes: Use of this indicator may require assistance from a soil scientist with local experience. An undisturbed sample must be observed. Individual strata are dominantly less than 1 in. (2.5 cm) thick. A hand lens can aid in the identification of this indicator. Many alluvial soils have stratified layers at depths greater than 6 in. (15 cm); these do not fit this indicator. Many alluvial soils have stratified layers at the required depths but lack a chroma of 2 or less; these do not fit this indicator. Stratified layers occur in any type of soil material, generally in floodplains and other areas where wet soils are subject to rapid and repeated burial with thin deposits of sediment.

Indicator A11: Depleted Below Dark Surface

Technical Description: A layer with a depleted or gleyed matrix that has 60 percent or more chroma of 2 or less, starting within 12 in. (30 cm) of the soil surface, and having a minimum thickness of either:

- 6 in. (15 cm), or
- 2 in. (5 cm) if the 2 in. (5 cm) consists of fragmental soil material.

Loamy/clayey layer(s) above the depleted or gleyed matrix must have a value of 3 or less and chroma of 2 or less. Any sandy material above the depleted or gleyed matrix must have a value of 3 or less and chroma of 1 or less and, when viewed with a 10- or 15-power hand lens, must have at least 70 percent of the visible soil particles masked with organic material. When viewed without a hand lens, the material appears to be nearly 100 percent masked.

Applicable Subregions: Applicable throughout the Northcentral and Northeast Region.

User Notes: This indicator often occurs in hydric soils that have dark-colored surface layers, such as umbric epipedons and dark-colored ochric epipedons (Figure 12). For soils that have dark surface layers greater than 12 in. (30 cm) thick, use indicator A12. Two percent or more distinct or prominent redox concentrations, including iron/manganese soft masses, pore linings, or both, are required in soils that have matrix values/ chromas of 4/1, 4/2, and 5/2 (Figure A1). If the soil is saturated at the time of sampling, it may be necessary to let it dry to a moist condition for redox features to become visible. See the Glossary (Appendix A) for definitions of depleted matrix, gleyed matrix, distinct and prominent features, and fragmental soil material.



Figure 12. In this soil, a depleted matrix starts immediately below the black surface layer at approximately 11 in. (28 cm).

In some places, the gleyed matrix may change color upon exposure to air (reduced matrix). This phenomenon is included in the concept of a gleyed matrix (USDA Natural Resources Conservation Service 2002).

This indicator is commonly found at the boundary of wetlands in Mollisols or other dark-colored soils. It is often found in soils formed on alluvial terraces along larger river systems in areas subject to ponding due to high water tables.

Indicator A12: Thick Dark Surface

Technical Description: A layer at least 6 in. (15 cm) thick with a depleted or gleyed matrix that has 60 percent or more chroma of 2 or less starting below 12 in. (30 cm) of the surface. The layer(s) above the depleted or gleyed matrix must have a value of 2.5 or less and chroma of 1 or less to a depth of at least 12 in. (30 cm) and a value of 3 or less and chroma of 1 or less in any remaining layers above the depleted or gleyed matrix. Any sandy material above the depleted or gleyed matrix, when viewed with a 10- or

15-power hand lens, must have at least 70 percent of the visible soil particles masked with organic material. When viewed without a hand lens, the material appears to be nearly 100 percent masked.

Applicable Subregions: Applicable throughout the Northcentral and Northeast Region.

User Notes: The soil has a depleted matrix or gleyed matrix below a black or very dark gray surface layer 12 in. (30 cm) or more thick (Figure 13). This indicator is most often associated with overthickened soils in concave landscape positions. Two percent or more distinct or prominent redox concentrations (Table A1), including iron/manganese soft masses, pore linings, or both, are required in soils that have matrix values/chromas of 4/1, 4/2, and 5/2 (Figure A1). If the soil is saturated at the time of sampling, it may be necessary to let it dry to a moist condition for redox features to become visible. See the Glossary (Appendix A) for the definitions of depleted and gleyed matrix.

In some places, the gleyed matrix may change color upon exposure to air (reduced matrix). This phenomenon is included in the concept of a gleyed matrix (USDA Natural Resources Conservation Service 2002).

This indicator is almost never found at the wetland/non-wetland boundary and is much less common than indicators A11 (Depleted Below Dark Surface), F3 (Depleted Matrix), and F6 (Redox Dark Surface).

Sandy soils

"Sandy soils" refers to soil materials with a USDA soil texture of loamy fine sand and coarser. Use the following indicators in soil layers consisting of sandy soil materials.

All mineral layers above any of the layers meeting an S indicator, except for indicator S6, must have a dominant chroma of 2 or less, or the layer(s) with a dominant chroma of more than 2 must be less than 6 in. (15 cm) thick to meet any hydric soil indicator. Nodules and concretions are not considered to be redox concentrations unless otherwise noted.



Figure 13. Deep observations may be necessary to identify the depleted or gleyed matrix below a thick, dark surface layer. In this example, the depleted matrix starts at 20 in. (50 cm).

Indicator S1: Sandy Mucky Mineral

Technical Description: A layer of mucky modified sandy soil material 2 in. (5 cm) or more thick starting within 6 in. (15 cm) of the soil surface (Figure 14).

Applicable Subregions: Applicable throughout the Northcentral and Northeast Region.

User Notes: This indicator is uncommon but is found in localized areas in this region. *Mucky* is a USDA texture modifier for mineral soils. The organic carbon content is at least 5 percent and ranges up to 14 percent for sandy soils. The percentage requirement is dependent upon the clay content of the soil; the higher the clay content, the higher the organic carbon



Figure 14. The mucky modified sandy layer is approximately 3 in. (7.5 cm) thick. Scale in inches on the right side of ruler.

requirement. See the glossary of *Field Indicators of Hydric Soils in the United States* (USDA Natural Resources Conservation Service 2010) for the definition of mucky modified mineral texture. A field procedure for identifying mucky mineral soil material is presented in the Concepts section of this chapter.

Indicator S4: Sandy Gleyed Matrix

Technical Description: A gleyed matrix that occupies 60 percent or more of a layer starting within 6 in. (15 cm) of the soil surface (Figure 15).

Applicable Subregions: Applicable throughout the Northcentral and Northeast Region.

User Notes: The gleyed matrix only has to be present within 6 in. (15 cm) of the surface. Soils with gleyed matrices are saturated for significant periods; therefore, *no minimum thickness of gleyed layer is required*. See the Glossary (Appendix A) for the definition of a gleyed matrix.

This indicator is most frequently found in tidal marshes and generally is not found at the boundaries between wetlands and non-wetlands.



Figure 15. In this example, the gleyed matrix begins at the soil surface.

Indicator S5: Sandy Redox

Technical Description: A layer starting within 6 in. (15 cm) of the soil surface that is at least 4 in. (10 cm) thick and has a matrix with 60 percent or more chroma of 2 or less with 2 percent or more distinct or prominent redox concentrations occurring as soft masses and/or pore linings (Figure 16).

Applicable Subregions: Applicable throughout the Northcentral and Northeast Region.

User Notes: Distinct and prominent are defined in the Glossary (Appendix A). Redox concentrations include iron and manganese masses (reddish mottles) and pore linings (Vepraskas 1992). Included within the concept of redox concentrations are iron/manganese bodies as soft masses with diffuse boundaries. Common (2 to less than 20 percent) to many (20 percent or more) redox concentrations (USDA Natural Resources Conservation Service 2002) are required. If the soil is saturated at the time of sampling, it may be necessary to let it dry to a moist condition for redox features to become visible.



Figure 16. Redox concentrations (orange areas) in sandy soil material.

This is a very common indicator of hydric soils and is often used to identify the hydric/non-hydric boundary in sandy soils. This indicator is often associated with depressions or swales in dune/swale complexes.

Indicator S6: Stripped Matrix

Technical Description: A layer starting within 6 in. (15 cm) of the soil surface in which iron/manganese oxides and/or organic matter have been stripped from the matrix and the primary base color of the soil material has been exposed. The stripped areas and translocated oxides and/or organic matter form a faintly contrasting pattern of two or more colors with diffuse boundaries. The stripped zones are 10 percent or more of the volume and are rounded.

Applicable Subregions: Applicable throughout the Northcentral and Northeast Region.

User Notes: This indicator includes the indicator previously named streaking (Environmental Laboratory 1987). The stripped areas are typically 0.5 to 1 in. (1 to 3 cm) in size but may be larger or smaller. Commonly, the stripped areas have a value of 5 or more and chroma of 1 and/or 2 and unstripped areas have a chroma of 3 and/or 4 (Figure 17).



Figure 17. In this example, a faint splotchy pattern of stripped and unstripped areas lies beneath a thin dark surface layer.

However, there are no specific color requirements for this indicator. The mobilization and translocation of the oxides and/or organic matter are the important processes involved in this indicator and should result in splotchy coated and uncoated soil areas. A 10-power hand lens can be helpful in seeing stripped and unstripped areas. This may be a difficult pattern to recognize and is often more evident in a horizontal slice.

This is a very common indicator of hydric soils and is often used to identify the hydric/non-hydric boundary in sandy soils. This indicator is found in all wetland types and all wet landscape positions.

Indicator S7: Dark Surface

Technical Description: A layer 4 in. (10 cm) thick starting within 6 in. (15 cm) of the soil surface with a matrix value of 3 or less and chroma of 1 or less. When viewed with a 10- or 15-power hand lens, at least 70 percent of

the visible soil particles must be masked with organic material. When viewed without a hand lens, the material appears to be nearly 100 percent masked. The matrix color of the layer immediately below the dark layer must have the same colors as those described above or any color that has a chroma of 2 or less.

Applicable Subregions: Applicable to the Northeastern Forests Subregion (LRR R) (Figure 1) and the Long Island/Cape Cod Subregion (MLRA 149B of LRR S) (Figure 18). For testing in LRRs K, L, and M.

User Notes: If the dark layer is greater than 4 in. (10 cm) thick, then the indicator is met, because any dark soil material in excess of 4 in. (10 cm) meets the requirement that "the layer immediately below the dark layer must have the same colors as those described above... ." If the dark layer is exactly 4 in. (10 cm) thick, then the material immediately below must have a matrix chroma of 2 or less.

This indicator is applicable to interdunal swales along the Atlantic Ocean. The organic carbon content of this indicator is slightly less than that required for "mucky." An undisturbed sample must be observed (Figure 19). Many moderately wet soils have a ratio of about 50 percent of soil particles covered or coated with organic matter to about 50 percent uncoated or uncovered soil particles, giving the soil a salt-and-pepper appearance. Where the percent coverage by organic matter is less than 70 percent, the Dark Surface indicator is not present.

Indicator S8: Polyvalue Below Surface

Technical Description: A layer with a value of 3 or less and chroma of 1 or less starting within 6 in. (15 cm) of the soil surface. When viewed with a 10- or 15-power hand lens, at least 70 percent of the visible soil particles in this layer must be masked with organic material. When viewed without a hand lens, the material appears to be nearly 100 percent masked. Immediately below this layer, 5 percent or more of the soil volume has a value of 3 or less and chroma of 1 or less and the remainder of the soil volume has a value of 4 or more and chroma of 1 or less to a depth of 12 in. (30 cm) or to the spodic horizon, whichever is less.

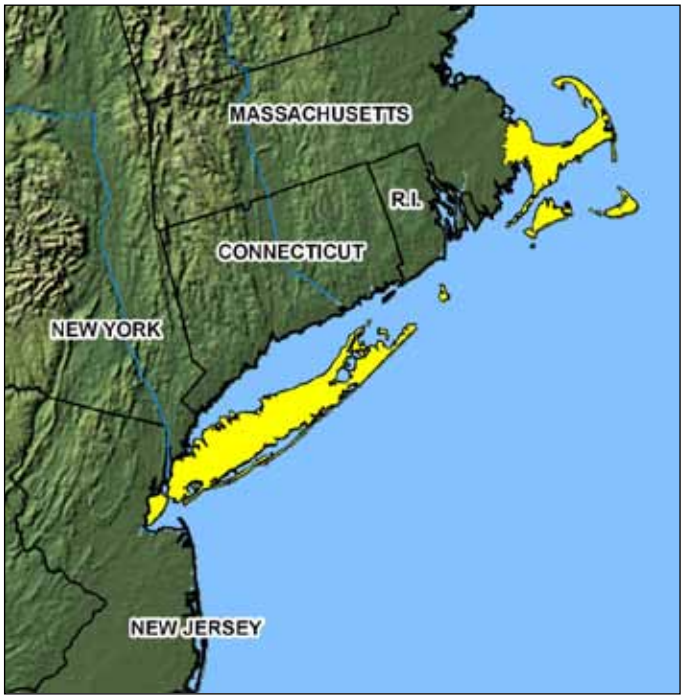


Figure 18. Location of MLRA 149B of LRR S.



Figure 19. Example of indicator S7 (Dark Surface) in a sandy soil. Scale in inches on right.

Applicable Subregions: Applicable to the Northeastern Forests Subregion (LRR R) (Figure 1) and the Long Island/Cape Cod Subregion (MLRA 149B of LRR S) (Figure 18).

User Notes: This indicator applies to soils with a very dark gray or black surface or near-surface layer that is underlain by a layer in which organic matter has been differentially distributed within the soil by water movement (Figure 20). The mobilization and translocation of organic matter result in splotchy coated and uncoated soil areas, as described in the Sandy Redox (S5) and Stripped Matrix (S6) indicators, except that for S8 the whole soil is in shades of black and gray. The chroma of 1 or less is critical because it limits application of this indicator to only those soils that are depleted of iron. This indicator includes the indicator previously termed "streaking." See *Soil Taxonomy* (USDA Natural Resources Conservation Service 1999) for the definition of spodic horizon.



Figure 20. In this soil, the splotchy pattern below the dark surface is due to mobilization and translocation of organic matter. Scale in inches.

Indicator S9: Thin Dark Surface

Technical Description: A layer 2 in. (5 cm) or more thick starting within the upper 6 in. (15 cm) of the soil, with a value of 3 or less and chroma of 1 or less. When viewed with a 10- or 15-power hand lens, at least 70 percent of the visible soil particles in this layer must be masked with organic material. When viewed without a hand lens, the material appears to be nearly 100 percent masked. This layer is underlain by a layer(s) with a value of 4 or less and chroma of 1 or less to a depth of 12 in. (30 cm) or to the spodic horizon, whichever is less.

Applicable Subregions: Applicable to the Northeastern Forests Subregion (LRR R) (Figure 1) and the Long Island/Cape Cod Subregion (MLRA 149B of LRR S) (Figure 18).

User Notes: This indicator applies to soils with a very dark gray or black near-surface layer that is at least 2 in. (5 cm) thick and is underlain by a layer in which organic matter has been carried downward by flowing water (Figure 21). The mobilization and translocation of organic matter result in an even distribution of organic matter in the eluvial (E) horizon. The chroma of 1 or less is critical because it limits application of this indicator to only those soils that are depleted of iron. This indicator commonly occurs in hydric Spodosols; however, a spodic horizon is not required. See *Soil Taxonomy* (USDA Natural Resources Conservation Service 1999) for the definitions of Spodosol and spodic horizon.



Figure 21. Example of indicator S9 (Thin Dark Surface). Scale in inches on right.

Loamy and clayey soils

"Loamy and clayey soils" refers to soil materials with USDA textures of loamy very fine sand and finer. Use the following indicators in soil layers consisting of loamy or clayey soil materials.

All mineral layers above any of the layers meeting an F indicator, except for indicators F8, F12, and F19, must have a dominant chroma of 2 or less, or the layer(s) with a dominant chroma of more than 2 must be less than 6 in. (15 cm) thick to meet any hydric soil indicator. Nodules and concretions are not considered to be redox concentrations unless otherwise noted.

Indicator F1: Loamy Mucky Mineral

Technical Description: A layer of mucky modified loamy or clayey soil material 4 in. (10 cm) or more thick starting within 6 in. (15 cm) of the soil surface.

Applicable Subregions: Applicable to the Northcentral Forests (LRR K) and Central Great Lakes Forests (LRR L) Subregions (Figure 1).

User Notes: *Mucky* is a USDA texture modifier for mineral soils. The organic carbon is at least 8 percent, but can range up to 18 percent. The percentage requirement is dependent upon the clay content of the soil; the higher the clay content, the higher the organic carbon requirement. See the Concepts section of this chapter for guidance on identifying mucky mineral soil materials in the field; however, loamy mucky soil material is difficult to distinguish without laboratory testing.

Indicator F2: Loamy Gleyed Matrix

Technical Description: A gleyed matrix that occupies 60 percent or more of a layer starting within 12 in. (30 cm) of the soil surface (Figure 22).

Applicable Subregions: Applicable throughout the Northcentral and Northeast Region.

User Notes: Gley colors are not synonymous with gray colors. Gley colors are those colors that are on the gley pages (Gretag/Macbeth 2000). They have hue N, 10Y, 5GY, 10GY, 5G, 10G, 5BG, 10BG, 5B, 10B, or 5PB, with



Figure 22. This soil has a gleyed matrix in the lowest layer, starting about 7 in. (18 cm) from the soil surface. The layer above the gleyed matrix has a depleted matrix.

value 4 or more. The gleyed matrix only has to be present within 12 in. (30 cm) of the surface. Soils with gleyed matrices are saturated for significant periods; therefore, no minimum thickness of gleyed layer is required. See the Glossary (Appendix A) for the definition of a gleyed matrix.

This indicator is found in soils that are inundated or saturated nearly all of the growing season in most years (e.g., in oxbows with permanent water) and is not usually found at the boundaries between wetlands and non-wetlands.

Indicator F3: Depleted Matrix

Technical Description: A layer that has a depleted matrix with 60 percent or more chroma of 2 or less and that has a minimum thickness of either:

- 2 in. (5 cm) if the 2 in. (5 cm) is entirely within the upper 6 in. (15 cm) of the soil, or
- 6 in. (15 cm) starting within 10 in. (25 cm) of the soil surface.

Applicable Subregions: Applicable throughout the Northcentral and Northeast Region.

User Notes: This is one of the most commonly observed hydric soil indicators at wetland boundaries. Redox concentrations including iron/manganese soft masses or pore linings, or both, are required in soils with matrix values/chromas of 4/1, 4/2, and 5/2 (Figures 23 and 24). If the soil is saturated at the time of sampling, it may be necessary to let it dry to a moist condition for redox features to become visible. Redox concentrations are not required in soils with matrix values of 5 or more and chroma of 1, or values of 6 or more and chromas of 2 or 1. The low-chroma matrix must be caused by wetness and not be a relict or parent material feature. See the Glossary (Appendix A) for the definition of a depleted matrix.



Figure 23. Example of indicator F3 (Depleted Matrix), in which redox concentrations extend nearly to the surface.



Figure 24. This soil has a depleted matrix with redox concentrations in a low-chroma matrix.

Indicator F6: Redox Dark Surface

Technical Description: A layer that is at least 4 in. (10 cm) thick, is entirely within the upper 12 in. (30 cm) of the mineral soil, and has a:

- matrix value of 3 or less and chroma of 1 or less and 2 percent or more distinct or prominent redox concentrations occurring as soft masses or pore linings, or
- matrix value of 3 or less and chroma of 2 or less and 5 percent or more distinct or prominent redox concentrations occurring as soft masses or pore linings.

Applicable Subregions: Applicable throughout the Northcentral and Northeast Region.

User Notes: This is a very common indicator used to delineate wetlands. Redox concentrations are often small and difficult to see in mineral soils that have dark (value of 3 or less) surface layers due to high organic-matter content (Figure 25). The organic matter masks some or all of the concentrations that may be present; it also masks the diffuse boundaries of



Figure 25. Redox features can be small and difficult to see within a dark soil layer.

the concentrations and makes them appear to be more sharp. Careful examination is required to see what are often brownish redox concentrations in the darkened materials. If the soil is saturated at the time of sampling, it may be necessary to let it dry at least to a moist condition for redox features to become visible. In some cases, further drying of the samples makes the concentrations (if present) easier to see. A hand lens may be helpful in seeing and describing small redox concentrations. Care should be taken to examine the interior of soil peds for redox concentrations. Dry colors, if used, also must have matrix chromas of 1 or 2, and the redox concentrations must be distinct or prominent. For soils with thick, dark surface layers, see also indicators A11 (Depleted Below Dark Surface) and A12 (Thick Dark Surface).

In soils that are wet because of subsurface saturation, the layer immediately below the dark epipedon will likely have a depleted or gleyed matrix (see the Glossary for definitions). Soils that are wet because of ponding or have a shallow, perched layer of saturation may not always have a

depleted/gleyed matrix below the dark surface. This morphology has been observed in soils that have been compacted by tillage and other means. It is recommended that delineators evaluate the hydrologic source and examine and describe the layer below the dark-colored epipedon when applying this indicator.

Indicator F7: Depleted Dark Surface

Technical Description: Redox depletions with a value of 5 or more and chroma of 2 or less in a layer that is at least 4 in. (10 cm) thick, is entirely within the upper 12 in. (30 cm) of the mineral soil (Figure 26), and has a:

- matrix value of 3 or less and chroma of 1 or less and 10 percent or more redox depletions, or
- matrix value of 3 or less and chroma of 2 or less and 20 percent or more redox depletions.



Figure 26. Redox depletions (lighter colored areas) are scattered within the darker matrix. Scale is in centimeters.

Applicable Subregions: Applicable throughout the Northcentral and Northeast Region.

User Notes: Care should be taken not to mistake the mixing of eluvial (leached) layers that have high value and low chroma (E horizon) or illuvial layers that have accumulated carbonates (calcic horizon) into the surface layer as depletions. Mixing of layers can be caused by burrowing animals or cultivation. Pieces of deeper layers that become incorporated into the surface layer are not redox depletions. Knowledge of local conditions is required in areas where light-colored eluvial layers and/or layers high in carbonates may be present. In soils that are wet because of subsurface saturation, the layer immediately below the dark surface is likely to have a depleted or gleyed matrix. Redox depletions are usually associated with microsites that have redox concentrations occurring as pore linings or masses within the depletion(s) or surrounding the depletion(s).

Indicator F8: Redox Depressions

Technical Description: In closed depressions subject to ponding, 5 percent or more distinct or prominent redox concentrations occurring as soft masses or pore linings in a layer that is 2 in. (5 cm) or more thick and is entirely within the upper 6 in. (15 cm) of the soil (Figure 27).



Figure 27. In this example, the layer of redox concentrations begins at the soil surface and is slightly more than 2 in. (5 cm) thick.

Applicable Subregions: Applicable throughout the Northcentral and Northeast Region.

User Notes: This indicator occurs on depressional landforms, such as vernal pools and potholes, but not microdepressions on convex landscapes. Closed depressions often occur within flats or floodplain landscapes. *Note that there is no color requirement for the soil matrix.* The layer containing redox concentrations may extend below 6 in. (15 cm) as long as at least 2 in. (5 cm) occurs within 6 in. (15 cm) of the surface. If the soil is saturated at the time of sampling, it may be necessary to let it dry to a moist condition for redox features to become visible. See the Glossary for definitions of distinct and prominent.

This is a common but often overlooked indicator found at the wetland/non-wetland boundary on depressional sites.

Hydric soil indicators for problem soils

The following indicators are not currently recognized for general application by the NTCHS, or they are not recognized in the specified geographic area. However, these indicators may be used in problem wetland situations in the Northcentral and Northeast Region where there is evidence of wetland hydrology and hydrophytic vegetation, and the soil is believed to meet the definition of a hydric soil despite the lack of other indicators of a hydric soil. To use these indicators, follow the procedure described in the section on Problematic Hydric Soils in Chapter 5. If any of the following indicators is observed, it is recommended that the NTCHS be notified by following the protocol described in the "Comment on the Indicators" section of *Field Indicators of Hydric Soils in the United States* (USDA Natural Resources Conservation Service 2010).

Indicator A10: 2 cm Muck

Technical Description: A layer of muck 0.75 in. (2 cm) or more thick with a value of 3 or less and chroma of 1 or less, starting within 6 in. (15 cm) of the soil surface.

Applicable Subregions: For use with problem soils in the Northcentral Forests (LRR K), Central Great Lakes Forests (LRR L), and Long Island/Cape Cod (MLRA 149B of LRR S) Subregions.

User Notes: Normally the muck layer is at the soil surface; however, it may occur at any depth within 6 in. (15 cm) of the surface. Muck is sapric soil material with at least 12 to 18 percent organic carbon. Organic soil material is called muck if virtually all of the material has undergone sufficient decomposition to limit recognition of the plant parts. Hemic (mucky peat) and fibric (peat) soil materials do not qualify. To determine if muck is present, first remove loose leaves, needles, bark, and other easily identified plant remains. This is sometimes called leaf litter, a duff layer, or a leaf or root mat. Then examine for decomposed organic soil material. Generally, muck is black and has a greasy feel; sand grains should not be evident (see the Concepts section of this chapter for field methods to identify organic soil materials). Determination of this indicator is made below the leaf or root mat; however, root mats that meet the definition of hemic or fibric soil material are included in the decision-making process for indicators A1 (Histosol) and A2 (Histic Epipedon).

Indicator A16: Coast Prairie Redox

Technical Description: A layer starting within 6 in. (15 cm) of the soil surface that is at least 4 in. (10 cm) thick and has a matrix chroma of 3 or less with 2 percent or more distinct or prominent redox concentrations occurring as soft masses and/or pore linings.

Applicable Subregions: For use with problem soils throughout the Northcentral and Northeast Region, *except* in the Long Island/Cape Cod Subregion (MLRA 149B of LRR S).

User Notes: These hydric soils occur mainly on depressional and intermound landforms. Redox concentrations occur mainly as iron-dominated pore linings. Common to many redox concentrations are required. If the soil is saturated at the time of sampling, it may be necessary to let it dry to a moist condition for redox features to become visible. Chroma 3 matrices are allowed because they may be the color of stripped sand grains, or because few to common sand-sized reddish particles may be present and may prevent obtaining a chroma of 2 or less.

Indicator S3: 5 cm Mucky Peat or Peat

Technical Description: A layer of mucky peat or peat 2 in. (5 cm) or more thick with a value of 3 or less and chroma of 2 or less, starting within 6 in. (15 cm) of the soil surface, and underlain by sandy soil material.

Applicable Subregions: For use with problem soils throughout the Northcentral and Northeast Region, *except* in the Long Island/Cape Cod Subregion (MLRA 149B of LRR S).

User Notes: In this region, this indicator is applicable primarily to interdunal swales along the Great Lakes and Atlantic coast. Mucky peat (hemic soil material) and peat (fibric soil material) have at least 12 to 18 percent organic carbon. Organic soil material is called peat if virtually all of the plant remains are sufficiently intact to permit identification of plant remains. Mucky peat is an intermediate stage of decomposition between peat and highly decomposed muck. See the glossary of Field Indicators of Hydric Soils in the United States (USDA Natural Resources Conservation Service 2010) for definitions. See the Concepts section of this chapter for field methods to identify organic soil materials.

Indicator S7: Dark Surface

Technical Description: A layer 4 in. (10 cm) thick starting within 6 in. (15 cm) of the soil surface with a matrix value of 3 or less and chroma of 1 or less. When viewed with a 10- or 15-power hand lens, at least 70 percent of the visible soil particles must be masked with organic material. When viewed without a hand lens, the material appears to be nearly 100 percent masked. The matrix color of the layer immediately below the dark layer must have the same colors as those described above or any color that has a chroma of 2 or less.

Applicable Subregions: For use with problem soils in the Northcentral Forests (LRR K) and Central Great Lakes Forests (LRR L) Subregions.

User Notes: This indicator is applicable to interdunal swales along the Great Lakes. See the User Notes for indicator S7 earlier in this chapter.

Indicator S8: Polyvalue Below Surface

Technical Description: A layer with a value of 3 or less and chroma of 1 or less starting within 6 in. (15 cm) of the soil surface. When viewed with a 10- or 15-power hand lens, at least 70 percent of the visible soil particles in this layer must be masked with organic material. When viewed without a hand lens, the material appears to be nearly 100 percent masked. Immediately below this layer, 5 percent or more of the soil volume has a value of 3 or less and chroma of 1 or less and the remainder of the soil

volume has a value of 4 or more and chroma of 1 or less to a depth of 12 in. (30 cm) or to the spodic horizon, whichever is less.

Applicable Subregions: For use with problem soils in the Northcentral Forests (LRR K) and Central Great Lakes Forests (LRR L) Subregions.

User Notes: See the User Notes for indicator S8 earlier in this chapter.

Indicator S9: Thin Dark Surface

Technical Description: A layer 2 in. (5 cm) or more thick starting within the upper 6 in. (15 cm) of the soil, with a value of 3 or less and chroma of 1 or less. When viewed with a 10- or 15-power hand lens, at least 70 percent of the visible soil particles in this layer must be masked with organic material. When viewed without a hand lens, the material appears to be nearly 100 percent masked. This layer is underlain by a layer(s) with a value of 4 or less and chroma of 1 or less to a depth of 12 in. (30 cm) or to the spodic horizon, whichever is less.

Applicable Subregions: For use with problem soils in the Northcentral Forests (LRR K) and Central Great Lakes Forests (LRR L) Subregions.

User Notes: See the User Notes for indicator S9 earlier in this chapter.

Indicator F12: Iron-Manganese Masses

Technical Description: On floodplains, a layer 4 in. (10 cm) or more thick with 40 percent or more chroma of 2 or less and 2 percent or more distinct or prominent redox concentrations occurring as soft iron-manganese masses with diffuse boundaries. The layer occurs entirely within 12 in. (30 cm) of the soil surface. Iron-manganese masses have a value and chroma of 3 or less. Most commonly, they are black. The thickness requirement is waived if the layer is the mineral surface layer.

Applicable Subregions: For use with problem soils throughout the Northcentral and Northeast Region, *except* in the Long Island/Cape Cod Subregion (MLRA 149B of LRR S).

User Notes: These iron-manganese masses generally are small (2 to 5 mm in size) and have value and chroma of 3 or less. They can be dominated by manganese and, therefore, have a color approaching black (Figure 28). If

the soil is saturated at the time of sampling, it may be necessary to let it dry to a moist condition for redox features to become visible. The low matrix chroma must be the result of wetness and not be a relict or parent material feature. Iron-manganese masses should not be confused with the larger and redder iron nodules associated with plinthite or with concretions that have sharp boundaries. This indicator occurs on floodplains such as those of the Mississippi, Hudson, and Penobscot Rivers.



Figure 28. Iron-manganese masses (black spots) in a 40 percent depleted matrix. Scale is in inches.

Indicator F19: Piedmont Floodplain Soils

Technical Description: On active floodplains, a mineral layer at least 6 in. (15 cm) thick starting within 10 in. (25 cm) of the soil surface with a matrix (60 percent or more of the volume) chroma of less than 4 and 20 percent or more distinct or prominent redox concentrations occurring as soft masses or pore linings.

Applicable Subregions: For use with problem soils in the Long Island/Cape Cod Subregion (MLRA 149B of LRR S) (Figure 18).

User Notes: This indicator is restricted to floodplains that are actively receiving sediments and groundwater discharge with high iron content (Figure 29). The soil chroma must be less than 4. If the soil is saturated at the time of sampling, it may be necessary to let it dry to a moist condition for redox features to become visible.



Figure 29. The Piedmont Floodplain Soils indicator is restricted to floodplains that are actively receiving sediments and groundwater discharge with high iron content. Photo by M. Rabenhorst. Scale in 4-in. (10-cm) increments.

Indicator F21: Red Parent Material

Technical Description: A layer derived from red parent materials (see glossary) that is at least 10 cm (4 inches) thick, starting within 25 cm (10 inches) of the soil surface with a hue of 7.5YR or redder. The matrix has a value and chroma greater than 2 and less than or equal to 4. The layer must contain 10 percent or more depletions and/or distinct or prominent redox concentrations occurring as soft masses or pore linings. Redox depletions should differ in color by having:

- value one or more higher and chroma one or more lower than the matrix, or
- value of 4 or more and chroma of 2 or less.

Applicable Subregions: For use with problem soils throughout the Northcentral and Northeast Region.

User Notes: This indicator was developed for use in areas of red parent material. In order to confirm that it is appropriate to apply this indicator to particular soils, soils formed from similar parent materials in the area should have been evaluated to determine their Color Change Propensity Index (CCPI) and be shown to have CCPI values below 30 (Rabenhorst and Parikh, 2000.) It cannot be assumed that sediment overlying red colored bedrock is derived solely from that bedrock. The total percentage of all redox concentrations and redox depletions must add up to at least 10% to meet the threshold for this indicator.

This indicator is typically found at the boundary between hydric and non-hydric soils. Users that encounter a depleted matrix in the upper part should consider F3-Depleted Matrix. F3 is often found in sites that are anaerobic for a longer period. Users that encounter a dark soil surface (value 3 or less and chroma 2 or less) should consider F6-Redox Dark Surface or F7-Depleted Dark Surface. If the site is in a closed depression subject to ponding users should consider F8-Redox Depressions. See glossary for definition of Red Parent Material.

Indicator TA6: Mesic Spodic

Technical Description: A layer 2 in. (5 cm) or more thick starting within 6 in. (15 cm) of the mineral soil surface that has a value of 3 or less and chroma of 2 or less and is underlain by either:

- a layer(s) 3 in. (8 cm) or more thick starting within 12 in. (30 cm) of the mineral soil surface that has a value and chroma of 3 or less and shows evidence of spodic development; or
- a layer(s) 2 in. (5 cm) or more thick starting within 12 in. (30 cm) of the mineral soil surface that has a value of 4 or more and chroma of 2 or less and is directly underlain by a layer(s) 3 in. (8 cm) or more thick with a value and chroma of 3 or less that shows evidence of spodic development.

Applicable Subregions: For use with problem soils in MLRAs 144A and 145 of LRR R and MLRA 149B of LRR S (Figure 30).

User Notes: This indicator is used to identify wet soils with spodic materials or that meet the definition of a Spodosol in MLRAs 144A and 145 of LRR R and MLRA 149B of LRR S only. The layer that has a value of 4 or more and chroma of 2 or less is typically described as an E or Eg horizon. These typically have color patterns described as stripped or partially

stripped matrices. The layer with evidence of spodic development is typically described as a Bh, Bhs, Bhsm, Bsm, or Bs horizon. These layers typically have color patterns or cementation indicative of the accumulation of translocated iron, aluminum, and/or organic matter.

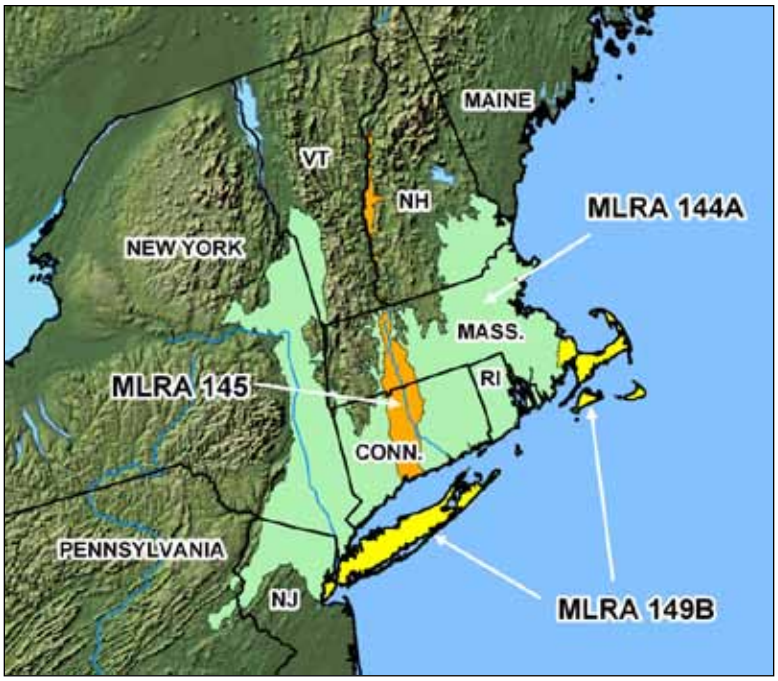


Figure 30. Location of MLRAs 144A and 145 in LRR R and MLRA 149B in LRR S.

Indicator TF12: Very Shallow Dark Surface

Technical Description: In depressions and other concave landforms, one of the following:

- If bedrock occurs between 6 in. (15 cm) and 10 in. (25 cm), a layer at least 6 in. (15 cm) thick starting within 4 in. (10 cm) of the soil surface with a value of 3 or less and chroma of 1 or less, and the remaining soil to bedrock must have the same colors as above or any other color that has a chroma of 2 or less.
- If bedrock occurs within 6 in. (15 cm), more than half of the soil thickness must have a value of 3 or less and chroma of 1 or less, and the remaining soil to bedrock must have the same colors as above or any other color that has a chroma of 2 or less.

Applicable Subregions: For use with problem soils throughout the Northcentral and Northeast Region.

4 Wetland Hydrology Indicators

Introduction

Wetland hydrology indicators are used in combination with indicators of hydric soil and hydrophytic vegetation to determine whether an area is a wetland under the Corps Manual. Indicators of hydrophytic vegetation and hydric soil generally reflect a site's medium- to long-term wetness history. They provide readily observable evidence that episodes of inundation or soil saturation lasting more than a few days during the growing season have occurred repeatedly over a period of years and that the timing, duration, and frequency of wet conditions have been sufficient to produce a characteristic wetland plant community and hydric soil morphology. If hydrology has not been altered, vegetation and soils provide strong evidence that wetland hydrology is present (National Research Council 1995). Wetland hydrology indicators provide evidence that the site has a *continuing* wetland hydrologic regime and that hydric soils and hydrophytic vegetation are not relicts of a past hydrologic regime. Wetland hydrology indicators confirm that an episode of inundation or soil saturation occurred recently, but may provide little additional information about the timing, duration, or frequency of such events (National Research Council 1995).

Hydrology indicators are often the most transitory of wetland indicators. Some hydrology indicators are naturally temporary or seasonal, and many are affected by recent or long-term meteorological conditions. For example, indicators involving direct observation of surface water or saturated soils often are present only during the normal wet portion of the growing season and may be absent during the dry season or during drier-than-normal years. Hydrology indicators also may be subject to disturbance or destruction by natural processes or human activities. Most wetlands in the Northcentral and Northeast Region will exhibit one or more of the hydrology indicators presented in this chapter. However, some wetlands may lack any of these indicators due to temporarily dry conditions, disturbance, or other factors. Therefore, the lack of an indicator is not evidence for the absence of wetland hydrology. See Chapter 5 (Difficult Wetland Situations in the Northcentral and Northeast Region) for help in identifying wetlands that may lack wetland hydrology indicators at certain times.

The Northcentral and Northeast Region has a humid, temperate climate with cold, snowy winters and moderate-to-abundant spring and summer rainfall in most areas and years. The dry season is less pronounced in this region than in the adjacent regions, but increased evapotranspiration during June, July, and August causes water tables to drop and surface water to recede from wetland margins. Particularly in seasonally saturated wetlands, hydrology indicators may be difficult to find during dry periods. On the other hand, some indicators may be present on non-wetland sites immediately after a heavy rain or during periods of unusually high precipitation, river stages, reservoir releases, runoff, or snowmelt. Therefore, it is important to consider weather and climatic conditions prior to the site visit to minimize both false-positive and false-negative wetland hydrology decisions. An understanding of normal seasonal and annual variations in rainfall, temperature, and other climatic conditions is important in interpreting hydrology indicators in the region. Some useful sources of climatic data are described in Chapter 5.

Areas that have hydrophytic vegetation and hydric soils generally also have wetland hydrology unless the hydrologic regime has changed due to natural events or human activities (National Research Council 1995). Therefore, when wetland hydrology indicators are absent from an area that has indicators of hydric soil and hydrophytic vegetation, further information may be needed to determine whether or not wetland hydrology is present. If possible, one or more site visits should be scheduled to coincide with the normal wet portion of the growing season, the period of the year when the presence or absence of wetland hydrology indicators is most likely to reflect the true wetland/non-wetland status of the site. In addition, aerial photography or other remote-sensing data, stream gauge data, monitoring well data, runoff estimates, scope-and-effect equations for ditches and subsurface drainage systems, or groundwater modeling are tools that may help to determine whether wetland hydrology is present when indicators are equivocal or lacking (e.g., USDA Natural Resources Conservation Service 1997). Off-site procedures developed under the National Food Security Act Manual (USDA Natural Resources Conservation Service 1994), which use wetland mapping conventions developed by NRCS state offices, can help identify areas that have wetland hydrology on agricultural lands. The technique is based on wetness signatures visible on standard high-altitude aerial photographs or on annual crop-compliance slides taken by the USDA Farm Service Agency. Finally, on highly disturbed or problematic sites, direct hydrologic monitoring may be needed to determine whether wetland

hydrology is present. The U.S. Army Corps of Engineers (2005) provides a technical standard for monitoring hydrology on such sites. This standard requires 14 or more consecutive days of flooding, ponding, and/or a water table 12 in. (30 cm) or less below the soil surface, during the growing season, at a minimum frequency of 5 years in 10 (50 percent or higher probability) (National Research Council 1995) unless an alternative standard has been established for a particular region or wetland type. See Chapter 5 for further information on these techniques.

Growing season

Beginning and ending dates of the growing season may be needed to evaluate certain wetland indicators, such as visual observations of flooding, ponding, or shallow water tables on potential wetland sites. In addition, growing season dates are needed in the event that recorded hydrologic data, such as stream gauge or water-table monitoring data, must be analyzed to determine whether wetland hydrology is present on highly disturbed or problematic sites.

Depletion of oxygen and the chemical reduction of nitrogen, iron, and other elements in saturated soils during the growing season is the result of biological activity occurring in plant roots and soil microbial populations (National Research Council 1995). Two indicators of biological activity that are readily observable in the field are (1) above-ground growth and development of vascular plants, and (2) soil temperature as an indicator of soil microbial activity (Megonigal et al. 1996, USDA Natural Resources Conservation Service 1999). If information about growing season is needed and on-site data gathering is practical, the following approaches should be used in this region to determine growing season dates in a given year. The growing season has begun and is ongoing if either of these conditions is met. Therefore, the beginning of the growing season in a given year is indicated by whichever condition occurs earlier, and the end of the growing season is indicated by whichever condition persists later.

1. The growing season has begun on a site in a given year when two or more different non-evergreen vascular plant species growing in the wetland or surrounding areas exhibit one or more of the following indicators of biological activity:

    a. Emergence of herbaceous plants from the ground

b. Appearance of new growth from vegetative crowns (e.g., in graminoids, bulbs, and corms)
c. Coleoptile/cotyledon emergence from seed
d. Bud burst on woody plants (i.e., some green foliage is visible between spreading bud scales)
e. Emergence or elongation of leaves of woody plants
f. Emergence or opening of flowers

The end of the growing season is indicated when woody deciduous species lose their leaves or the last herbaceous plants cease flowering and their leaves become dry or brown, whichever occurs latest. These changes generally take place in the fall due to cold temperatures or reduced moisture availability. Early plant senescence due to the initiation of the summer dry season in some areas does not necessarily indicate the end of the growing season and alternative procedures (e.g., soil temperature) should be used.

Determinations of the beginning or the end of the growing season should not include evergreen species, including such herbaceous species as *Polystichum acrostichoides* and *Lycopodium* spp. or deciduous species that retain their leaves into the winter (e.g., *Rhamnus cathartica*). Certain herbaceous plants, such as *Alliaria petiolata*, *Carex blanda*, *Geum canadense*, and *Hesperis matronalis*, have basal rosettes and lower stem leaves that retain chlorophyll and remain green throughout the year, including winter (Figure 31). The winter presence of green tissue in these species is not considered a vegetative signal that the growing season has begun. These types of herbaceous species do not indicate the beginning or end of the growing season. If limited to using these types of species, look for new growth from the vegetative crowns to meet the biological activity indicator.

Observations should be made in the wetland or in surrounding areas subject to the same climatic conditions (e.g., similar elevation and aspect); however, soil moisture conditions and plant communities may differ. Supporting data should be reported on the data form, in field notes, or in the delineation report, and should include the species observed (if identifiable), their abundance and location relative to the potential wetland, and type of biological activity observed. A one-time observation of biological activity during a single site visit is sufficient,

but is not required unless growing season information is necessary to evaluate particular wetland hydrology indicators. However, if long-term hydrologic monitoring is planned, then plant growth, maintenance, and senescence should be monitored for continuity over the same period.



Figure 31. A caution in determining the start of the growing season using the "green up" indicator. Certain herbaceous species produce overwintering green leaves. An example is Dame's rocket (*Hesperis matronalis*) where the stem, stem leaves, and flowers die back at the end of the growing season, but a basal rosette of green leaves persists under the snowpack. The photograph above, which was taken immediately following the first exposure of the ground surface after snowmelt, illustrates this characteristic.

2. The growing season has begun in spring, and is still in progress, when soil temperature measured at 12 in. (30 cm) depth is 41 °F (5 °C) or higher. A one-time temperature measurement during a single site visit is sufficient, but is not required unless growing season information is necessary to evaluate particular wetland hydrology indicators. However, if long-term hydrologic monitoring is planned, then soil temperature should also be monitored to ensure that it remains continuously at or above 41 °F during the monitoring period. Soil temperature can be measured directly in the field by inserting a soil thermometer into the wall of a freshly dug soil pit. Measurements should be made in the wetland or in surrounding areas subject to the same climatic conditions (e.g., similar elevation and aspect); however, soil moisture conditions may differ.

If the timing of the growing season based on vegetation growth and development and/or soil temperature is unknown and on-site data collection is not practical, such as when analyzing previously recorded stream-gauge or monitoring-well data, then growing season dates may be approximated by the median dates (i.e., 5 years in 10, or 50 percent probability) of 28 °F (−2.2 °C) air temperatures in spring and fall, based on long-term records gathered at National Weather Service meteorological stations (U.S. Army Corps of Engineers 2005). These dates are reported in WETS tables available from the NRCS National Water and Climate Center (http://www.wcc.nrcs.usda.gov/climate/wetlands.html) for the nearest appropriate weather station.

Wetland hydrology indicators

In this chapter, wetland hydrology indicators are presented in four groups. Indicators in Group A are based on the direct observation of surface water or groundwater during a site visit. Group B consists of evidence that the site is subject to flooding or ponding, although it may not be inundated currently. These indicators include water marks, drift deposits, sediment deposits, and similar features. Group C consists of other evidence that the soil is saturated currently or was saturated recently (e.g., oxidized rhizospheres surrounding living roots and the presence of reduced iron or sulfur in the soil profile). Group D consists of landscape, soil, and vegetation features that indicate contemporary rather than historical wet conditions. Wetland hydrology indicators are intended as one-time observations of site conditions that are sufficient evidence of wetland hydrology. Unless otherwise noted, all indicators are applicable throughout the Northcentral and Northeast Region.

Within each group, indicators are divided into two categories – *primary* and *secondary* – based on their estimated reliability in this region. One primary indicator from any group is sufficient to conclude that wetland hydrology is present; the area is a wetland if indicators of hydric soil and hydrophytic vegetation are also present. In the absence of a primary indicator, two or more secondary indicators from any group are required to conclude that wetland hydrology is present. Indicators of wetland hydrology include, but are not necessarily limited to, those listed in Table 10 and described on the following pages. Other evidence of wetland hydrology may also be used with appropriate documentation.

Table 10. Wetland hydrology indicators for the Northcentral and Northeast Region

Indicator	Category	
	Primary	Secondary
Group A – Observation of Surface Water or Saturated Soils		
A1 – Surface water	X	
A2 – High water table	X	
A3 – Saturation	X	
Group B – Evidence of Recent Inundation		
B1 – Water marks	X	
B2 – Sediment deposits	X	
B3 – Drift deposits	X	
B4 – Algal mat or crust	X	
B5 – Iron deposits	X	
B7 – Inundation visible on aerial imagery	X	
B8 – Sparsely vegetated concave surface	X	
B9 – Water-stained leaves	X	
B13 – Aquatic fauna	X	
B15 – Marl deposits	X	
B6 – Surface soil cracks		X
B10 – Drainage patterns		X
B16 – Moss trim lines		X
Group C – Evidence of Current or Recent Soil Saturation		
C1 – Hydrogen sulfide odor	X	
C3 – Oxidized rhizospheres along living roots	X	
C4 – Presence of reduced iron	X	
C6 – Recent iron reduction in tilled soils	X	
C7 – Thin muck surface	X	
C2 – Dry-season water table		X
C8 – Crayfish burrows		X
C9 – Saturation visible on aerial imagery		X
Group D – Evidence from Other Site Conditions or Data		
D1 – Stunted or stressed plants		X
D2 – Geomorphic position		X
D3 – Shallow aquitard		X
D4 – Microtopographic relief		X
D5 – FAC-neutral test		X

In this supplement, wetland hydrology indicators that have depth requirements (e.g., indicator A2 – High Water Table) are evaluated from the mineral soil surface or the top of any organic soil layer, whichever is shallower. Organic layers consist of dead and decomposing plant matter. Therefore, observations should start below any living material (e.g., a living mat of mosses, lichens, etc.). The organic layer, if present, can be either saturated or unsaturated and of any thickness. Therefore, on some sites, the surface for hydric soil determinations (see Chapter 3) and wetland hydrology determinations may differ.

Group A – Observation of Surface Water or Saturated Soils

Indicator A1: Surface water

Category: Primary

General Description: This indicator consists of the direct, visual observation of surface water (flooding or ponding) during a site visit (Figure 32).

Cautions and User Notes: Care must be used in applying this indicator because surface water may be present in non-wetland areas immediately after a rainfall event or during periods of unusually high precipitation, runoff, tides, or river stages. Furthermore, some non-wetlands flood frequently for brief periods. Surface water observed during the non-growing season may be an acceptable indicator if experience and professional judgment suggest that wet conditions normally extend into the growing season for sufficient duration in most years. If this is questionable and other hydrology indicators are absent, a follow-up visit during the growing season may be needed. Water perched on seasonally frozen soil is included in this indicator if the resulting inundation is normally present well into the growing season. Note that surface water may be absent from a wetland during the normal dry season or during extended periods of drought. Even under normal rainfall conditions, some wetlands do not become inundated or saturated every year (i.e., wetlands are inundated or saturated at least 5 out of 10 years, or 50 percent or higher probability). In addition, groundwater-dominated wetland systems may never or rarely contain surface water.



Figure 32. Wetland with surface water present.

Indicator A2: High water table

Category: Primary

General Description: This indicator consists of the direct, visual observation of the water table 12 in. (30 cm) or less below the surface in a soil pit, auger hole, or shallow monitoring well (Figure 33). This indicator includes water tables derived from perched water, throughflow, and discharging groundwater (e.g., in seeps) that may be moving laterally near the soil surface.

Cautions and User Notes: Sufficient time must be allowed for water to infiltrate into a newly dug hole and to stabilize at the water-table level. The required time will vary depending upon soil texture. In some cases, the water table can be determined by examining the wall of the soil pit and identifying the upper level at which water is seeping into the pit. A water table within 12 in. (30 cm) of the surface observed during the non-growing season may be an acceptable indicator if experience and professional



Figure 33. High water table observed in a soil pit.

judgment suggest that wet conditions normally extend into the growing season for sufficient duration in most years. If this is questionable and other hydrology indicators are absent, a follow-up visit during the growing season may be needed. Water perched on seasonally frozen soil is included in this indicator if the resulting high water table is normally present well into the growing season. Care must be used in interpreting this indicator because water-table levels normally vary seasonally and are a function of both recent and long-term precipitation. Even under normal rainfall conditions, some wetlands do not become inundated or saturated every year (i.e., wetlands are inundated or saturated at least 5 out of 10 years, or 50 percent or higher probability). For an accurate determination of the water-table level, the soil pit, auger hole, or well should not penetrate any restrictive soil layer capable of perching water near the surface.

Indicator A3: Saturation

Category: Primary

General Description: Visual observation of saturated soil conditions 12 in. (30 cm) or less from the soil surface as indicated by water glistening on the surfaces and broken interior faces of soil samples removed from the pit or auger hole (Figure 34). This indicator must be associated with an existing water table located immediately below the saturated zone; however, this requirement is waived under episaturated conditions if there is a restrictive soil layer or bedrock within 12 in. (30 cm) of the surface.



Figure 34. Water glistens on the surface of a saturated soil sample.

Cautions and User Notes: Glistening is evidence that the soil sample was taken either below the water table or within the saturated capillary fringe above the water table. Recent rainfall events and the proximity of the water table at the time of sampling must be considered in applying and interpreting this indicator. Water observed in soil cracks or on the faces of soil aggregates (peds) does not meet this indicator unless ped interiors are also saturated. Depth to the water table must be recorded on the data form or in field notes. A water table is not required below the saturated zone under episaturated conditions if the restrictive layer or bedrock is present within 12 in. (30 cm) of the surface. Note the restrictive layer in the soils section of the data form. The restrictive layer may be at the surface.

Group B – Evidence of Recent Inundation

Indicator B1: Water marks

Category: Primary

General Description: Water marks are discolorations or stains on the bark of woody vegetation, rocks, bridge supports, buildings, fences, or other fixed objects as a result of inundation (Figure 35).



Figure 35. Water marks (light-colored areas) on trees in a seasonally flooded wetland.

Cautions and User Notes: When several water marks are present, the highest reflects the maximum extent of inundation. Water marks indicate a water-level elevation and can be extrapolated from nearby objects across lower elevation areas. Water marks on different trees or other objects should form a level plane that can be viewed from one object to another. Use caution with water marks that may have been caused by extreme, infrequent, or very brief flooding events, or by flooding that occurred outside the growing season. In areas with altered hydrology, use care with relict water marks that may reflect the historic rather than the current hydrologic regime. In regulated systems, such as reservoirs, water-level records can be used to distinguish unusually high pools from normal operating levels. This indicator does not include lines caused by ice scour or abrasion, which are indicated by bark or tissue damage.

Indicator B2: Sediment deposits

Category: Primary

General Description: Sediment deposits are thin layers or coatings of fine-grained mineral material (e.g., silt or clay) or organic matter (e.g., pollen), sometimes mixed with other detritus, remaining on tree bark (Figure 36), plant stems or leaves, rocks, and other objects after surface water recedes.



Figure 36. Silt deposit left after a recent high-water event forms a tan coating on these tree trunks (upper edge indicated by the arrow).

Cautions and User Notes: Sediment deposits most often occur in riverine backwater and ponded situations and indicate where water has stood for sufficient time to allow suspended sediment to settle. The upper edge of the sediment deposit reflects a water-surface elevation that can be extrapolated across lower elevation areas. Sediment deposits may remain for considerable periods before being removed by precipitation or subsequent inundation. Use caution with sediment left after infrequent high flows or very brief flooding events, such as those caused by ice jams. This indicator does not include thick accumulations of sand or gravel in fluvial channels that may reflect historic flow conditions or recent extreme events. Use caution in areas where silt and other material trapped in the snowpack may be deposited directly on the ground surface during spring thaw.

Indicator B3: Drift deposits

Category: Primary

General Description: Drift deposits consist of rafted debris that has been deposited on the ground surface or entangled in vegetation or other fixed objects. Debris consists of remnants of vegetation (e.g., branches, stems, and leaves), man-made litter, or other waterborne materials. Drift material may be deposited at or near the high water line in ponded or flooded areas, piled against the upstream sides of trees, rocks, and other fixed objects (Figure 37), or widely distributed within the dewatered area.



Figure 37. Drift deposit on the upstream side of a sapling in a floodplain wetland.

Cautions and User Notes: Deposits of drift material are often found adjacent to streams or other sources of flowing water in wetlands. They also occur in tidal marshes, along lake shores, and in other ponded areas. The elevation of a drift line can be extrapolated across lower elevation areas. Use caution with drift lines that may have been caused by extreme, infrequent, or very brief flooding events, debris piles not related to flooding or ponding, and in areas with functioning drainage systems capable of removing excess water quickly.

Indicator B4: Algal mat or crust

Category: Primary

General Description: This indicator consists of a mat or dried crust of algae, perhaps mixed with other detritus, left on or near the soil surface after dewatering.

Cautions and User Notes: Algal deposits include but are not limited to those produced by green algae (Chlorophyta) and blue-green algae (cyanobacteria). They may be attached to low vegetation or other fixed

objects, or may cover the soil surface (Figure 38). Dried crusts of blue-green algae may crack and curl at plate margins (Figure 39). Algal deposits are usually seen in seasonally ponded areas, lake fringes (e.g., *Cladophora* in the Great Lakes), tidal areas, and low-gradient stream margins. They reflect prolonged wet conditions sufficient for algal growth and development.



Figure 38. Dried algal deposit clinging to low vegetation.

Indicator B5: Iron deposits

Category: Primary

General Description: This indicator consists of a thin orange or yellow crust or gel of oxidized iron on the ground surface or on objects near the surface.

Cautions and User Notes: Iron deposits form in areas where reduced iron discharges with groundwater and oxidizes upon exposure to air. The oxidized iron forms a film or sheen on standing water and an orange or yellow deposit (Figures 40 and 41) on the ground surface or objects above the surface after dewatering.



Figure 39. Dried crust of blue-green algae on the soil surface.



Figure 40. Iron deposit (orange streaks) in a small channel.



Figure 41. At this site, ferrous iron moves with the groundwater from a cattail marsh to a shallow ditch, where it oxidizes when exposed to the air and forms an orange-colored iron deposit.

Indicator B7: Inundation visible on aerial imagery

Category: Primary

General Description: One or more recent aerial photographs or satellite images show the site to be inundated.

Cautions and User Notes: Care must be used in applying this indicator because surface water may be present on a non-wetland site immediately after a heavy rain or during periods of unusually high precipitation, runoff, tides, or river stages. See Chapter 5 for procedures to evaluate the normality of precipitation. Surface water observed during the non-growing season may be an acceptable indicator if experience and professional judgment suggest that wet conditions normally extend into the growing season for sufficient duration in most years. If this is questionable and other hydrology indicators are absent, additional photos or a site visit during the growing season may be needed. Surface water may be absent from a wetland during the normal dry season or during extended periods of drought. Even under normal rainfall conditions, some wetlands do not become inundated or

saturated every year (i.e., wetlands are inundated or saturated at least 5 out of 10 years, or 50 percent or higher probability). It is recommended that multiple years of photography be evaluated. If 5 or more years of aerial photography are available, the procedure described by the USDA Natural Resources Conservation Service (1997, section 650.1903) is recommended (see Chapter 5, section on Wetlands that Periodically Lack Indicators of Wetland Hydrology, for additional information). Record the date and source of the photography in the remarks section of the data form or in the delineation report.

Indicator B8: Sparsely vegetated concave surface

Category: Primary

General Description: On concave land surfaces (e.g., depressions and swales), the ground surface is either unvegetated or sparsely vegetated (less than 5 percent ground cover) due to long-duration ponding during the growing season (Figure 42).



Figure 42. A sparsely vegetated, seasonally ponded depression. Note the watermarks on trees.

Cautions and User Notes: Ponding during the growing season can limit the establishment and growth of ground-layer vegetation. Sparsely vegetated concave surfaces should contrast with vegetated slopes and convex surfaces in the same area. A woody overstory of trees or shrubs may or may not be present. Examples in the region include concave positions on floodplains, potholes, and seasonally ponded depressions in forested areas.

Indicator B9: Water-stained leaves

Category: Primary

General Description: Water-stained leaves are fallen or recumbent dead leaves that have turned grayish or blackish in color due to inundation for long periods.

Cautions and User Notes: Water-stained leaves are most often found in depressional wetlands (e.g., vernal pools) and along streams in shrub-dominated or forested habitats; however, they also occur in herbaceous communities. Staining often occurs in leaves that are in contact with the soil surface while inundated for long periods (Figure 43). Overlapping leaves may become matted together due to wetness and decomposition. Water-stained leaves maintain their blackish or grayish colors when dry. They should contrast strongly with fallen leaves in nearby non-wetland landscape positions.



Figure 43. Water-stained leaves in a seasonally ponded depression, with an unstained leaf (right center) for comparison.

Indicator B13: Aquatic fauna

Category: Primary

General Description: Presence of live individuals, diapausing insect eggs or crustacean cysts, or dead remains of aquatic fauna, such as, but not limited to, clams, aquatic snails, aquatic insects, ostracods, shrimp, other crustaceans, tadpoles, or fish, either on the soil surface or clinging to plants or other emergent objects.

Cautions and User Notes: Examples of dead remains include clam shells, chitinous exoskeletons, insect head capsules, aquatic snail shells (Figure 44), and skins or skeletons of aquatic amphibians or fish (Figure 45). Aquatic fauna or their remains should be reasonably abundant; one or two individuals are not sufficient. Use caution in areas where faunal remains may have been transported by high winds, unusually high water, or other animals into non-wetland areas. Shells and exoskeletons are resistant to tillage but may be moved by equipment beyond the boundaries of the wetland. They may also persist in the soil for years after dewatering.



Figure 44. Shells of aquatic snails in a seasonally ponded fringe wetland.



Figure 45. Dead green frogs (*Rana clamitans melanota*) in a drying seasonal pool.

Indicator B15: Marl deposits

Category: Primary

General Description: This indicator consists of the presence of marl on the soil surface.

Cautions and User Notes: Marl deposits consist mainly of calcium carbonate precipitated from standing or flowing water through the action of algae or diatoms. Marl appears as a tan or whitish deposit on the soil surface after dewatering (Figure 46) and may form thick deposits in some areas. Subsurface marl layers in some soils do not qualify for this indicator. Marl deposits are found mainly in calcareous fens, seeps, or white cedar swamps in areas underlain by limestone bedrock.

Indicator B6: Surface soil cracks

Category: Secondary

General Description: Surface soil cracks consist of shallow cracks that form when fine-grained mineral or organic sediments dry and shrink, often creating a network of cracks or small polygons (Figure 47).

Cautions and User Notes: Surface soil cracks are often seen in fine sediments and in areas where water has ponded long enough to destroy surface soil structure in depressions, lake fringes, and floodplains. Use caution, however, as they may also occur in temporary ponds and puddles



Figure 46. Marl deposit (tan-colored areas) and iron sheen in a calcareous fen.



Figure 47. Surface soil cracks in a seasonally ponded depression.

in non-wetlands and in areas that have been effectively drained. This indicator does not include deep cracks due to shrink-swell action in clay soils, such as those in the Lake Champlain Valley and in Vertisols.

Indicator B10: Drainage patterns

Category: Secondary

General Description: This indicator consists of flow patterns visible on the soil surface or eroded into the soil, low vegetation bent over in the direction of flow, absence of leaf litter or small woody debris due to flowing water, and similar evidence that water flowed across the ground surface.

Cautions and User Notes: Drainage patterns are usually seen in areas where water flows broadly over the surface and is not necessarily confined to a channel, such as in areas adjacent to streams, in seeps, and swales that convey surface water (Figures 48, 49, and 50). Use caution in areas subject to high winds or affected by recent unusual flooding events, and in vegetated swales in upland areas.



Figure 48. Drainage patterns seen during typical early spring flows in a forested wetland. The patterns are also evident when the wetland is dry.



Figure 49. Drainage patterns in a slope wetland.



Figure 50. Vegetation bent over in the direction of water flow across a stream terrace.

Indicator B16: Moss trim lines

Category: Secondary

General Description: Presence of moss trim lines on trees or other upright objects in seasonally inundated areas.

Cautions and User Notes: Moss trim lines (Figure 51) are formed when water-intolerant mosses growing on tree trunks and other upright objects are killed by prolonged inundation, forming an abrupt lower edge to the moss community at the high-water level (Carr et al. 2006). They are occasionally seen in floodplains and ponded areas throughout the region. Trim lines on different trees in the inundated area should indicate the same water-level elevation. The elevation of a trim line can be extrapolated across lower elevation areas in the vicinity. This indicator does not include lines caused by ice scour or abrasion, which are indicated by bark or tissue damage, and does not include trim lines in lichens which, due to slow regrowth, may reflect unusually high or infrequent flooding events. Certain species of aquatic mosses and liverworts are tolerant of long-duration inundation and occur on trees and other objects below the high-water level. Therefore, the lack of a trim line does not indicate that the site does not pond or flood.



Figure 51. Moss trim lines in a seasonally flooded wetland. Trim lines indicate a recent high-water level.

Group C – Evidence of Current or Recent Soil Saturation

Indicator C1: Hydrogen sulfide odor

Category: Primary

General Description: A hydrogen sulfide (rotten egg) odor within 12 in. (30 cm) of the soil surface.

Cautions and User Notes: Hydrogen sulfide is a gas produced by soil microbes in response to prolonged saturation in soils where oxygen, nitrogen, manganese, and iron have been largely reduced and there is a source of sulfur. For hydrogen sulfide to be detectable, the soil must be saturated at the time of sampling and must have been saturated long enough to become highly reduced. These soils are often permanently saturated and anaerobic at or near the surface. To apply this indicator, dig the soil pit no deeper than 12 in. to avoid release of hydrogen sulfide from deeper in the profile. Hydrogen sulfide odor serves as both an indicator of hydric soil and wetland hydrology. This single observation proves that the soil meets the definition of a hydric soil (i.e., anaerobic in the upper part), plus has an ongoing wetland hydrologic regime. Often these soils have a high water table (wetland hydrology indicator A2), but the hydrogen sulfide odor provides further proof that the soil has been saturated for a long period of time.

Indicator C3: Oxidized rhizospheres along living roots

Category: Primary

General Description: Presence of a layer of any thickness containing 2 percent or more iron-oxide coatings or plaques on the surfaces of living roots and/or iron-oxide coatings or linings on soil pores immediately surrounding living roots within 12 in. (30 cm) of the surface.

Cautions and User Notes: Oxidized rhizospheres are the result of oxygen leakage from living roots into the surrounding anoxic soil, causing oxidation of ferrous iron present in the soil solution. They are evidence of saturated and reduced soil conditions during the plant's lifetime. Iron concentrations or plaques may form on the immediate root surface or may coat the soil pore adjacent to the root (Figures 52 and 53). In either case, the oxidized iron must be associated with living roots to indicate

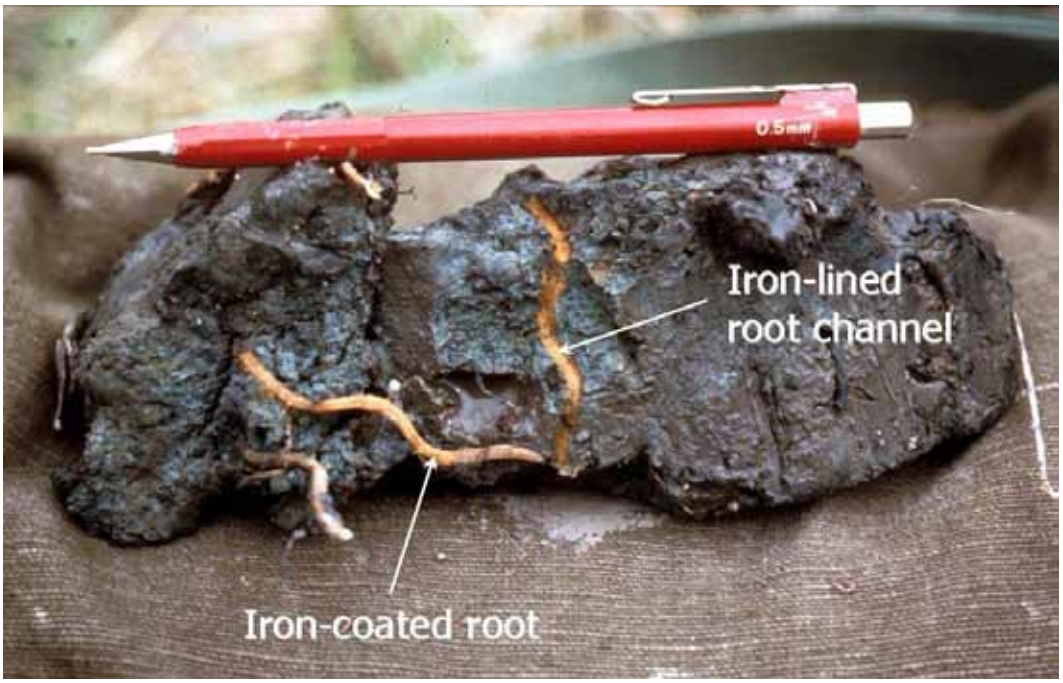


Figure 52. Iron-oxide plaque (orange coating) on a living root. Iron also coats the channel or pore from which the root was removed.



Figure 53. This soil has many oxidized rhizospheres associated with living roots.

contemporary wet conditions and to distinguish these features from other pore linings. Care must be taken to distinguish iron-oxide coatings from organic matter associated with plant roots. Viewing with a hand lens may help to distinguish mineral from organic material and to identify oxidized rhizospheres along fine roots and root hairs. Iron coatings sometimes show concentric layers in cross section and may transfer iron stains to the fingers when rubbed. Note the location and abundance of oxidized rhizospheres in the soil profile description or remarks section of the data form. There is no minimum thickness requirement for the layer containing oxidized rhizospheres. Oxidized rhizospheres must occupy at least 2 percent of the volume of the layer.

Indicator C4: Presence of reduced iron

Category: Primary

General Description: Presence of a layer containing reduced (ferrous) iron in the upper 12 in. (30 cm) of the soil profile, as indicated by a ferrous iron test or by the presence of a soil that changes color upon exposure to the air.

Cautions and User Notes: The reduction of iron occurs in soils that have been saturated long enough to become anaerobic and chemically reduced. Ferrous iron is converted to oxidized forms when saturation ends and the soil reverts to an aerobic state. Thus, the presence of ferrous iron indicates that the soil is saturated and/or anaerobic at the time of sampling. The presence of ferrous iron can be verified with alpha, alpha-dipyridyl reagent (Figure 54) or by observing a soil that changes color upon exposure to air (i.e., reduced matrix). A positive reaction to alpha, alpha-dipyridyl should occur over more than 50 percent of the soil layer in question. The reagent does not react when wetlands are dry; therefore, a negative test result is not evidence that the soil is not reduced at other times of year. Soil samples should be tested or examined immediately after opening the soil pit because ferrous iron may oxidize and colors change soon after the sample is exposed to the air. Avoid areas of the soil that may have been in contact with iron digging tools. Soils that contain little weatherable iron may not react even when saturated and reduced. There are no minimum thickness requirements or initial color requirements for the soil layer in question.



Figure 54. When alpha, alpha-dipyridyl is applied to a soil containing reduced iron, a positive reaction is indicated by a pink or red coloration to the treated area.

Indicator C6: Recent iron reduction in tilled soils

Category: Primary

General Description: Presence of a layer containing 2 percent or more redox concentrations as pore linings or soft masses in the tilled surface layer of soils cultivated within the last two years. The layer containing redox concentrations must be within the tilled zone or within 12 in. (30 cm) of the soil surface, whichever is shallower.

Cautions and User Notes: Cultivation breaks up or destroys redox features in the plow zone. The presence of redox features that are continuous and unbroken indicates that the soil was saturated and reduced since the last episode of cultivation (Figure 55). Redox features often form around organic material, such as crop residue, incorporated into the tilled soil. Use caution with older features that may be broken up but not destroyed by tillage. Newly formed redox concentrations should have diffuse boundaries. The indicator is most reliable in areas that are cultivated regularly, so that soil aggregates and older redox features are more likely to be broken up. If not obvious, information about the timing of last cultivation may be available from the land owner, other knowledgeable



Figure 55. Redox concentrations in the tilled surface layer of a recently cultivated soil.

individuals, aerial photography, or the Farm Service Agency. A plow zone of 6 to 8 in. (15 to 20 cm) in depth is typical but may extend deeper. There is no minimum thickness requirement for the layer containing redox concentrations.

Indicator C7: Thin muck surface

Category: Primary

General Description: This indicator consists of a layer of muck 1 in. (2.5 cm) or less thick at the soil surface.

Cautions and User Notes: Muck is highly decomposed (i.e., sapric) organic material that is associated with wetness (see the Concepts section of Chapter 3 for guidance on identifying muck). In this region, muck accumulates where soils are saturated to the surface for long periods each year. A thin muck layer on the soil surface indicates an active wetland hydrologic regime because thin muck surfaces disappear quickly or become incorporated into mineral horizons when wetland hydrology is withdrawn. On the other hand, thick muck layers can persist for years after wetland hydrology is effectively removed, as in many drained muck soils that are used to grow vegetable crops throughout the region.

Although thick muck layers also occur in wetlands, a muck layer greater than 1 in. thick does not qualify for this indicator. Use caution in areas with folistic surface layers (see the Concepts section of Chapter 3).

Indicator C2: Dry-season water table

Category: Secondary

General Description: Visual observation of the water table between 12 and 24 in. (30 and 60 cm) below the surface during the normal dry season or during a drier-than-normal year.

Cautions and User Notes: Due to normal seasonal fluctuations, water tables in wetlands often drop below 12 in. during the summer dry season. A water table between 12 and 24 in. during the dry season, or during an unusually dry year, likely indicates a normal wet-season water table within 12 in. of the surface. Sufficient time must be allowed for water to infiltrate into a newly dug hole and to stabilize at the water-table level. The required time will vary depending upon soil texture. In some cases, the water table can be determined by examining the wall of the soil pit and identifying the upper level at which water is seeping into the pit. For an accurate determination of the water-table level, the soil pit, auger hole, or well should not penetrate any restrictive soil layer capable of perching water near the surface. Water tables in wetlands often drop well below 24 in. during dry periods. Therefore, a dry-season water table below 24 in. does not necessarily indicate a lack of wetland hydrology. See Chapter 5 (section on Wetlands that Periodically Lack Indicators of Wetland Hydrology) to determine average dry-season dates and drought periods. In the Remarks section of the data form or in a separate report, provide documentation for the conclusion that the site visit occurred during the normal dry season, recent rainfall has been below normal, or the area has been affected by drought. This indicator does not apply in agricultural areas that have controlled drainage structures for subsurface irrigation.

Indicator C8: Crayfish burrows

Category: Secondary

General Description: Presence of crayfish burrows, as indicated by openings in soft ground up to 2 in. (5 cm) in diameter, often surrounded by chimney-like mounds of excavated mud.

Cautions and User Notes: Crayfish breathe with gills and require at least periodic contact with water. Some species dig burrows for refuge and breeding (Figure 56). Crayfish burrows are usually found near streams, ditches, and ponds in areas that are seasonally inundated or have seasonal high water tables at or near the surface. They are also found in wet meadows and pastures where there is no open water. Crayfish may extend their burrows 10 ft (3 m) or more in depth to keep pace with a falling water table; thus, the eventual depth of the burrow does not reflect the level of the seasonal high water table.



Figure 56. Crayfish burrow in a saturated wetland.

Indicator C9: Saturation visible on aerial imagery

Category: Secondary

General Description: One or more recent aerial photographs or satellite images indicate soil saturation. Saturated soil signatures must correspond to field-verified hydric soils, depressions or drainage patterns, differential crop management, or other evidence of a seasonal high water table.

Cautions and User Notes: This indicator is useful when plant cover is sparse or absent and the ground surface is visible from above. Saturated areas generally appear as darker patches within the field (Figure 57).

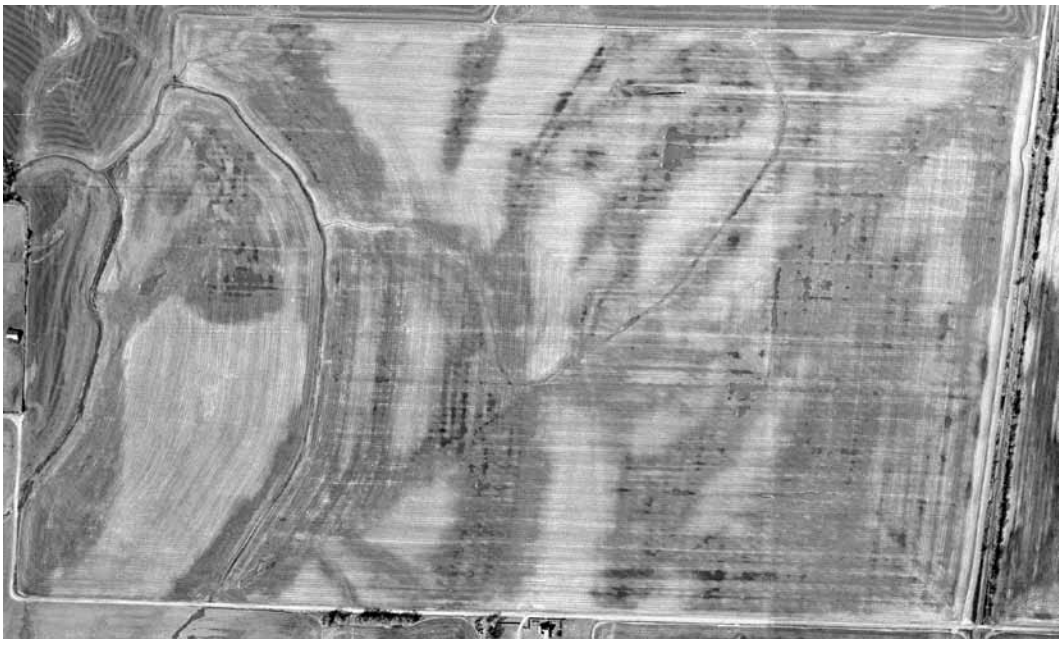


Figure 57. Aerial photograph of an agricultural field with saturated soils indicated by darker colors.

Saturated areas are often more evident on color infrared imagery. Inundated (indicator B7) and saturated areas may be present in the same field; if they cannot be distinguished, then use indicator C9 for the entire wet area. Care must be used in applying this indicator because saturation may be present on a non-wetland site immediately after a heavy rain or during periods of abnormally high precipitation, runoff, or river stages. Saturation observed during the non-growing season may be an acceptable indicator if experience and professional judgment suggest that wet conditions normally extend into the growing season for sufficient duration in most years. If this is questionable and other hydrology indicators are absent, additional photos or a site visit during the growing season may be needed. Saturation may be absent from a wetland during the normal dry season or during extended periods of drought. Even under normal rainfall conditions, some wetlands do not become inundated or saturated every year (i.e., wetlands are inundated or saturated at least 5 out of 10 years, or 50 percent or higher probability). It is recommended that multiple years of photography be evaluated. If 5 or more years of aerial photography are available, the procedure described by the Natural Resources Conservation Service (1997, section 650.1903, and associated state wetland mapping conventions) is recommended in actively farmed areas. Use caution, as similar signatures may be caused by factors other than saturation. This indicator requires on-site verification that saturation signatures seen on photos correspond to hydric soils or other evidence of a seasonal high

water table. This may be a useful tool for identifying the presence and location of subsurface drainage lines in current or former agricultural fields, and multiple years of photos may be helpful in evaluating the frequency and extent of soil saturation. This method may be inconclusive in areas with dark soil surfaces. Record the date and source of the photography in the Remarks section of the data form or in a separate report.

Group D – Evidence from Other Site Conditions or Data

Indicator D1: Stunted or stressed plants

Category: Secondary

General Description: This indicator is present if individuals of the same species growing in the potential wetland are clearly of smaller stature, less vigorous, or stressed compared with individuals growing in nearby non-wetland situations (Figures 58 and 59).

Cautions and User Notes: Some plant species can become established and grow in both wetlands and non-wetlands but may exhibit obvious stunting, yellowing, or stress in wet situations. This indicator is applicable to natural plant communities as well as agricultural crops and other introduced or planted vegetation. For this indicator to be present, a majority of individuals in the stand must be stunted or stressed. The comparison with



Figure 58. Stunted corn due to wet spots in an agricultural field in New Hampshire.



Figure 59. Black spruce in the wetland (foreground) are stressed and stunted compared with spruce in the adjacent areas (background).

individuals in non-wetland situations may be accomplished over a broad area and is not limited to the project site. Use caution in areas where stunting of plants on non-wetland sites may be caused by low soil fertility, excessively drained soils, cold temperatures, uneven application of agricultural chemicals, salinity, or other factors. In this region, this indicator is often seen in black spruce, red spruce, and balsam fir, as well as agricultural crops and other introduced or planted species.

Indicator D2: Geomorphic position

Category: Secondary

General Description: This indicator is present if the immediate area in question is located in a depression, drainageway, concave position within a floodplain, at the toe of a slope, on the low-elevation fringe of a pond or other water body, or in an area where groundwater discharges.

Cautions and User Notes: Excess water from precipitation and snowmelt naturally accumulates in certain geomorphic positions in the landscape, particularly in low-lying areas such as depressions, drainageways, toe slopes (Figure 6), and fringes of water bodies below any obvious terraces (Figure 60). These areas often, but not always, exhibit wetland hydrology. This indicator is not applicable in areas with functioning drainage systems and does not include concave positions on rapidly permeable soils (e.g., floodplains with sand and gravel substrates) that do not have wetland hydrology unless the water table is near the surface.



Figure 60. Fringes of water bodies, such as this estuarine fringe, are likely to exhibit wetland hydrology.

Indicator D3: Shallow aquitard

Category: Secondary

General Description: This indicator consists of the presence of an aquitard within 24 in. (60 cm) of the soil surface that is potentially capable of perching water within 12 in. (30 cm) of the surface.

Cautions and User Notes: An aquitard is a relatively impermeable soil layer or bedrock that slows the downward infiltration of water, and can produce a perched water table. In some cases, the aquitard may be at the surface (e.g., in clay soils) and cause water to pond on the surface. Potential aquitards in this region include dense glacial till, lacustrine deposits, fragipans, iron-cemented layers (e.g., ortstein), and clay layers. An aquitard can often be identified by the limited root penetration through the layer and/or the presence of redoximorphic features in the layer(s) above the aquitard. Local experience and professional judgment should indicate that the perched water table is likely to occur during the growing season for sufficient duration in most years. Soil layers that are seasonally frozen do not qualify as aquitards unless they are observed to perch water for long periods during the growing season. Use caution in areas with functioning drainage systems that are capable of removing perched water quickly.

Indicator D4: Microtopographic Relief

Category: Secondary

General Description: This indicator consists of the presence of microtopographic features that occur in areas of seasonal inundation or shallow water tables, such as hummocks, tussocks, and flark-and-strang topography, with microhighs less than 36 in. (90 cm) above the base soil level (Figure 61).



Figure 61. This hemlock-dominated wetland has trees growing on hummocks and herbaceous plants growing in tussocks.

Cautions and User Notes: These features are the result of vegetative and geomorphic processes in wetlands and produce the characteristic microtopographic diversity of some wetland systems. Microtopographic lows are either inundated or have shallow water tables for long periods each year. Microtopographic highs may or may not have wetland hydrology, but usually are small, narrow, or fragmented, often occupying less than half of the surface area. If indicators of hydrophytic vegetation or hydric soil are absent from microhighs, see the procedure for wetland/non-wetland mosaics in Chapter 5. This indicator does not include uneven topography due to vegetation-covered rocks, logs, or other debris, or trampling by livestock.

Indicator D5: FAC-neutral test

Category: Secondary

General Description: The plant community passes the FAC-neutral test.

Cautions and User Notes: The FAC-neutral test is performed by compiling a list of dominant plant species across all strata in the community, and dropping from the list any species with a Facultative indicator status (i.e., FAC). The FAC-neutral test is met if more than 50 percent of the remaining dominant species are rated FACW and/or OBL. This indicator can be used in communities that contain no FAC dominants. If there are an equal number of dominants that are OBL and FACW versus FACU and UPL, or if all dominants are FAC, non-dominant species should be considered.

5 Difficult Wetland Situations in the Northcentral and Northeast Region

Introduction

Some wetlands can be difficult to identify because wetland indicators may be missing due to natural processes or recent disturbances. This chapter provides guidance for making wetland determinations in difficult-to-identify wetland situations in the Northcentral and Northeast Region. It includes regional examples of problem area wetlands and atypical situations as defined in the Corps Manual, as well as other situations that can make wetland delineation more challenging. Problem area wetlands are naturally occurring wetland types that lack indicators of hydrophytic vegetation, hydric soil, or wetland hydrology periodically due to normal seasonal or annual variability, or permanently due to the nature of the soils or plant species on the site. Atypical situations are wetlands in which vegetation, soil, and/or hydrology indicators are absent due to recent human activities or natural events. In addition, this chapter addresses certain procedural problems (e.g., wetland/non-wetland mosaics) that can make wetland determinations in the region difficult or confusing. The chapter is organized into the following sections:

- Lands Used for Agriculture and Silviculture
- Problematic Hydrophytic Vegetation
- Problematic Hydric Soils
- Wetlands that Periodically Lack Indicators of Wetland Hydrology
- Wetland/Non-Wetland Mosaics

The list of difficult wetland situations presented in this chapter is not intended to be exhaustive and other problematic situations may exist in the region. See the Corps Manual for general guidance. Furthermore, more than one wetland factor (i.e., vegetation, soil, and/or hydrology) may be disturbed or problematic on a given site. In general, *wetland determinations on difficult or problematic sites must be based on the best information available to the field inspector, interpreted in light of his or her professional experience and knowledge of the ecology of wetlands in the region*.

Lands used for agriculture and silviculture

Agriculture and silviculture are important land uses in the Northcentral and Northeast Region, and both of these activities present challenges to wetland identification and delineation. Wetlands used for agriculture or silviculture often lack a natural plant community and may be planted to crops, pasture species, or desirable tree species and may be altered by mowing, grazing, herbicide use, or other management practices. Soils may be disturbed by cultivation, land clearing, grading, or bedding, at least in the surface layers, and hydrology may or may not be manipulated. Some areas that are used for agriculture or silviculture still retain wetland hydrology. In other areas, historic wetlands have been effectively drained and no longer meet wetland hydrology standards. Relict wetland indicators may still be present in these areas, making it difficult to distinguish current wetlands from those that have been effectively drained. In addition, agricultural activities can include improved groundwater management, involving the manipulation of water tables to conserve both water and nutrients (e.g., Frankenberger et al. 2006).

Agricultural and silvicultural drainage systems use ditches, subsurface drainage lines or "tiles," and water-control structures to manipulate the water table and improve conditions for crops or other desired species. A freely flowing ditch or drainage line depresses the water table within a certain lateral distance or zone of influence (Figure 62). The effectiveness of drainage in an area depends in part on soil characteristics, the timing and amount of rainfall, and the depth and spacing of ditches or drains. Wetland determinations on current and former agricultural or silvicultural lands must consider whether a drainage system is present, how it is designed to function, and whether it is effective in removing wetland hydrology from the area.

A number of information sources and tools are listed below to help determine whether wetlands are present on lands where vegetation, soils, hydrology, or a combination of these factors have been manipulated. Some of these options are discussed in more detail later in this chapter under the appropriate section headings.

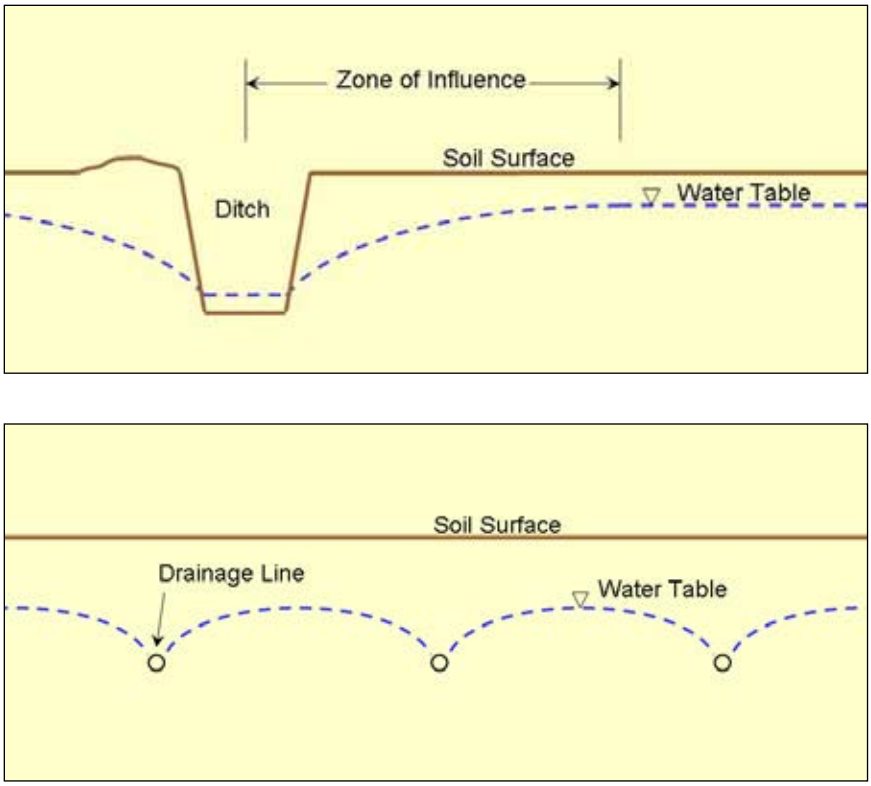


Figure 62. Effects of ditches (upper) and parallel subsurface drainage lines (lower) on the water table.

1. **Vegetation** – The goal is to determine the plant community that would occupy the site under normal circumstances, if the vegetation were not cleared or manipulated.

   a. Examine the site for volunteer vegetation that emerges between cultivations, plantings, mowings, or other treatments.
   b. Examine the vegetation on an undisturbed reference area with soils and hydrology similar to those on the site.
   c. Check NRCS soil survey reports for information on the typical vegetation on soil map units (hydrology of the site must be unaltered).
   d. If the conversion to agriculture or silviculture was recent and the hydrology of the site was not manipulated, examine pre-disturbance aerial photography, NWI maps, and other sources for information on the previous vegetation.
   e. Cease the clearing, cultivation, or manipulation of the site for one or more growing seasons with normal rainfall and examine the plant community that develops.

2. **Soils** – Tilling of agricultural land mixes the surface layer(s) of the soil and may cause compaction below the tilled zone (i.e., a "plow pan") due to the weight and repeated passage of farm machinery. Similar disturbance to surface soils may also occur in areas managed for silviculture. Nevertheless, a standard soil profile description and examination for hydric soil indicators are often sufficient to determine whether hydric soils are present. Other options and information sources include the following:

    a. Examine NRCS soil survey maps and the local hydric soils list for the likely presence of hydric soils on the site.
    b. Examine the soils on an undisturbed reference area with landscape position, parent materials, and hydrology similar to those on the site.
    c. Use alpha, alpha-dipyridyl reagent to check for the presence of reduced iron during the normal wet portion of the growing season, or note whether the soil changes color upon exposure to the air.
    d. Monitor the site in relation to the appropriate wetland hydrology or hydric soils technical standard.

3. **Hydrology** – The goal is to determine whether wetland hydrology is present on a managed site under normal circumstances, as defined in the Corps Manual and subsequent guidance. These sites may or may not have been hydrologically manipulated.

    a. Examine the site for existing indicators of wetland hydrology. If the natural hydrology of the site has been permanently altered, discount any indicators known to have been produced before the alteration (e.g., relict water marks or drift lines).
    b. In agricultural areas (e.g., row crops, hayfields, tree farms, nurseries, orchards, and others) examine five or more years of aerial photographs for wetness signatures listed in Part 513.30 of the National Food Security Act Manual (USDA Natural Resources Conservation Service 1994) or in wetland mapping conventions available from NRCS offices or online in the electronic Field Office Technical Guide (eFOTG) (http://www.nrcs.usda.gov/technical/efotg/). Use the procedure given by the USDA Natural Resources Conservation Service (1997) to determine whether wetland hydrology is present.
    c. Estimate the effects of ditches and subsurface drainage systems using scope-and-effect equations (USDA Natural Resources Conservation Service 1997). A web application to analyze data using various models is available at http://www.wli.nrcs.usda.gov/technical/web_tool/tools_java.html.

Scope-and-effect equations are approximations only and may not reflect actual field conditions. Their results should be verified by comparison with other techniques for evaluating drainage and should not overrule onsite evidence of wetland hydrology.

d. Use state drainage guides to estimate the effectiveness of an existing drainage system (USDA Natural Resources Conservation Service 1997). Drainage guides may be available from NRCS offices. Cautions noted in item *c* above also apply to the use of drainage guides. In addition, Corps of Engineers district offices should be consulted for locally developed techniques to evaluate wetland drainage.
e. Use hydrologic models (e.g., runoff, surface water, and groundwater models) to determine whether wetland hydrology is present (e.g., USDA Natural Resources Conservation Service 1997).
f. Monitor the hydrology of the site in relation to the appropriate wetland hydrology technical standard (U. S. Army Corps of Engineers 2005).

Problematic hydrophytic vegetation

Description of the problem

Many factors affect the structure and composition of plant communities in the region, including climatic variability, spread of exotic species, agricultural and silvicultural use, and other human land-use practices. As a result, some wetlands may exhibit indicators of hydric soil and wetland hydrology but lack any of the hydrophytic vegetation indicators presented in Chapter 2, at least at certain times. To identify and delineate these wetlands may require special sampling procedures or additional analysis of factors affecting the site. To the extent possible, the hydrophytic vegetation decision should be based on the plant community that is normally present during the wet portion of the growing season in a normal rainfall year. The following procedure addresses several examples of problematic vegetation situations in the Northcentral and Northeast Region.

Procedure

Problematic hydrophytic vegetation can be identified using a combination of observations made in the field and/or supplemental information from the scientific literature and other sources. These procedures should be applied only where indicators of hydric soil and wetland hydrology are present, unless one or both of these factors is also disturbed or

problematic, but no indicators of hydrophytic vegetation are evident. The following procedures are recommended:

1. Verify that at least one indicator of hydric soil and one primary or two secondary indicators of wetland hydrology are present. If indicators of either hydric soil or wetland hydrology are absent, the area is likely non-wetland unless soil and/or hydrology are also disturbed or problematic. If indicators of hydric soil and wetland hydrology are present (or are absent due to disturbance or other problem situations), proceed to step 2.

2. Verify that the area is in a landscape position that is likely to collect or concentrate water. If the landscape setting is appropriate, proceed to step 3. Appropriate settings include the following.

    a. Concave surface (e.g., depression or swale)
    b. Active floodplain or low terrace
    c. Level or nearly level area (e.g., 0- to 3-percent slope)
    d. Toe slope (Figure 6) or an area of convergent slopes (Figure 5)
    e. Fringe of another wetland or water body
    f. Area with a restrictive soil layer or aquitard within 24 in. (60 cm) of the surface
    g. Area where groundwater discharges (e.g., a seep)
    h. Other (explain in field notes why this area is likely to be inundated or saturated for long periods)

3. Use one or more of the approaches described in step 4 (Specific Problematic Vegetation Situations below) or step 5 (General Approaches to Problematic Hydrophytic Vegetation on page 131) to determine whether the vegetation is hydrophytic. In the remarks section of the data form or in the delineation report, explain the rationale for concluding that the plant community is hydrophytic even though indicators of hydrophytic vegetation described in Chapter 2 were not observed.

4. Specific Problematic Vegetation Situations

    a. *Temporal shifts in vegetation.* As described in Chapter 2, the species composition of some wetland plant communities in the region can change in response to seasonal weather patterns and long-term climatic fluctuations. Wetland types that are influenced by these shifts include Great Lakes coastal wetlands, vernal pools, interdunal swales,

wet meadows, wet prairies, seeps, and springs. Lack of hydrophytic vegetation during the dry season, when FACU and UPL warm-season grasses and annuals dominate many areas, should not immediately eliminate a site from consideration as a wetland, because the site may have been dominated by wetland species earlier in the growing season. A site qualifies for further consideration if the plant community at the time of sampling does not exhibit hydrophytic vegetation indicators, but indicators of hydric soil and wetland hydrology are present or known to be disturbed or problematic. The following sampling and analytical approaches are recommended in these situations:

(1) Seasonal Shifts in Plant Communities

(a) If possible, return to the site during the normal wet portion of the growing season (generally in early spring) and re-examine the site for indicators of hydrophytic vegetation.
(b) Examine the site for identifiable plant remains, either alive or dead, or other evidence that the plant community that was present during the normal wet portion of the growing season was hydrophytic.
(c) Use off-site data sources to determine whether the plant community that is normally present during the wet portion of the growing season is hydrophytic. Appropriate data sources include early growing season aerial photography, NWI maps, soil survey reports, remotely sensed data, public interviews, state wetland conservation plans, and previous reports about the site. If necessary, re-examine the site early in the growing season to verify the hydrophytic vegetation determination.
(d) If the vegetation on the site is substantially the same as that on a wetland reference site having similar soils, landscape position, and known wetland hydrology, then consider the vegetation to be hydrophytic (see step *5c* in this procedure for more information).
(e) If the hydrophytic status of the vegetation during the normal wet portion of the growing season in a normal rainfall year cannot be determined, make the wetland determination based on indicators of hydric soil and wetland hydrology.

(2) Prolonged Dry to Drought Conditions (lasting more than one growing season)

(a) Investigate climate records (e.g., WETS tables, drought indices) to determine if the area is under the influence of a drought or prolonged dry conditions (for more information, see the section on Wetlands that Periodically Lack Indicators of Wetland Hydrology later in this chapter). If so, evaluate any off-site data that provide information on the plant community that exists on the site during normal years, including aerial photography, Farm Service Agency annual crop slides, NWI maps, other remote sensing data, soil survey reports, public interviews, NRCS hydrology tools (USDA Natural Resources Conservation Service 1997), and previous site reports. Determine whether the vegetation that is present during normal years is hydrophytic.

(b) If the vegetation on the affected site is substantially the same as that on a wetland reference site in the same general area having similar soils and known wetland hydrology, then consider the vegetation to be hydrophytic (see step *5c* in this procedure).

(c) If the hydrophytic status of the vegetation during the normal wet portion of the growing season in a normal rainfall year cannot be determined, make the wetland determination based on indicators of hydric soil and wetland hydrology.

(3) Long-Term Fluctuations in Lake Levels. Water levels in lakes and ponds rise and fall depending upon annual precipitation patterns. These changes may induce short- or long-term shifts in fringing vegetation depending upon the duration of the wet or dry conditions. The Great Lakes have experienced significant periodic fluctuations in water levels since the early part of the twentieth century. During years with high lake levels, large areas of coastal vegetation may be inundated and converted to open water. During periods with low lake levels, some fringe wetlands may dry out and their vegetation may shift to non-hydrophytic plant communities. Similar vegetation changes may be observed on a smaller scale around the margins of other lakes and ponds across the North-central and Northeast Region (Tiner 2005). To determine the plant community that is present during normal lake levels, the following approaches are recommended.

(a) Determine whether water levels have been higher or lower than the long-term average by examining current and historical water-level data, such as those available for the Great Lakes from the Corps of Engineers Detroit District (http://www.lre.usace.army.mil/greatlakes/hh/greatlakeswaterlevels/). If water levels have been appreciably higher or lower than average for two or more consecutive years, examine off-site data sources to determine whether the plant community that is present on the site during years with normal lake levels is hydrophytic. Appropriate data sources include early growing-season aerial photography taken during normal years, NWI maps, soil survey reports, other remotely sensed data, interviews with the land owner and other knowledgeable people, state wetland conservation plans, and previous reports about the site.

(b) Examine the existing vegetation on the site, emphasizing long-lived woody and other perennial plant species. Discount annual and other short-lived species that may have become established during the period of unusually high or low lake levels.

(c) If the vegetation on the site is substantially the same as that on a wetland reference site on the same lake having similar soils, landscape position, and known wetland hydrology, then consider the vegetation to be hydrophytic (see step *5c* in this procedure for more information).

(d) If the hydrophytic status of the vegetation during years with normal lake levels cannot be determined, make the wetland determination based on indicators of hydric soil and wetland hydrology.

b. *Vernal pools*. Vernal pools are small, seasonal water bodies that pond water from the time of snowmelt into early to mid-summer. They are common throughout the glaciated Northcentral and Northeast Region, although most remaining pools are located in forested settings. The pools may be situated within wetlands or non-wetlands. They are characterized by vernal-pool-specific fauna, particularly amphibians and invertebrates that require the pools to complete their life cycles (Colburn 2004). The vegetation in and around these pools is influenced by the seasonal hydrology. During the early part of the growing season, they may lack herbaceous vegetation due to inundation and it may be necessary to base the hydrophytic vegetation decision solely on woody plants. Where woody vegetation is lacking, herbaceous

vegetation should be examined later in the growing season. In pools that retain water for very long periods, vegetation may not become well established even during drier periods. During the driest times of the year, or in drought years, some pools become dominated by upland plants, particularly annuals. The following approaches are recommended for evaluating vernal pools where indicators of hydric soil and wetland hydrology are present, but hydrophytic vegetation is not evident at the time of the site visit.

(1) If the pool is filled with water at the time of the visit, emergent vegetation is absent, and a follow-up site visit is practical, then return to the site soon after seasonal draw-down and check for indicators of hydrophytic vegetation.

(2) If the site is visited during the dry season, vegetation in the potential pool area is dominated by upland species (particularly annuals), and a follow-up site visit is practical, then revisit the site during the normal wet portion of the growing season and check again for indicators of hydrophytic vegetation.

(3) If the hydrophytic status of the vegetation during the normal wet portion of the growing season in a normal rainfall year cannot be determined, make the wetland determination based on indicators of hydric soil and wetland hydrology.

c. *Areas affected by grazing*. Both short- and long-term grazing can cause shifts in dominant species in the vegetation. For instance, trampling by large herbivores can cause soil compaction, altering soil permeability and infiltration rates, and affecting the plant community. Grazers can also influence the abundance of plant species by selectively grazing certain palatable species or avoiding less palatable species. This shift in species composition due to grazing can influence the hydrophytic vegetation determination. Be aware that shifts in both directions, favoring either wetland species or upland species, can occur in these situations. Limited grazing does not necessarily affect the outcome of a hydrophytic vegetation decision. However, the following approaches are recommended in cases where the effects of grazing are so great that the hydrophytic vegetation determination would be unreliable or misleading.

(1) Examine the vegetation on a nearby, ungrazed reference site having similar soils and hydrologic conditions. Ungrazed areas may be present on adjacent properties or in fenced exclosures or stream-side management zones. Assume that the same plant community would exist on the grazed site, in the absence of grazing.

(2) If feasible, remove livestock or fence representative livestock exclusion areas to allow the vegetation time to recover from grazing, and reevaluate the vegetation during the next growing season.

(3) If grazing was initiated recently, use offsite data sources such as aerial photography, NWI maps, and interviews with the land owner and other persons familiar with the site or area to determine what plant community was present on the site before grazing began. If the previously ungrazed community was hydrophytic, then consider the current vegetation to be hydrophytic.

(4) If an appropriate ungrazed area cannot be located or if the ungrazed vegetation condition cannot be determined, make the wetland determination based on indicators of hydric soils and wetland hydrology.

d. *Managed plant communities.* Natural plant communities throughout the region have been replaced with agricultural crops or are otherwise managed to meet human goals. Examples include clearing of woody species on grazed pasture land; periodic disking, plowing, or mowing; planting of native and non-native species (including cultivars or planted species that have escaped and become established on other sites); use of herbicides; silvicultural activities; and suppression of wildfires. These actions can result in elimination of certain species and their replacement with other species, changes in abundance of certain plants, and shifts in dominant species, possibly influencing a hydrophytic vegetation determination. The following approaches are recommended if the natural vegetation has been altered through management to such an extent that a hydrophytic vegetation determination is not possible or would be unreliable:

(1) Examine the vegetation on a nearby, unmanaged reference site having similar soils and hydrologic conditions. Assume that the same plant community would exist on the managed site in the

absence of human alteration.

(2) For recently cleared or tilled areas (not planted or seeded), leave representative areas unmanaged for at least one growing season with normal rainfall and reevaluate the vegetation.

(3) If management was initiated recently, use offsite data sources such as aerial photography, NWI maps, and interviews with the land owner and other persons familiar with the area to determine what plant community was present on the site before the management occurred.

(4) If the unmanaged vegetation condition cannot be determined, make the wetland determination based on indicators of hydric soil and wetland hydrology.

e. *Areas affected by fires, floods, and other natural disturbances.* Fires, floods, and other natural disturbances can dramatically alter the vegetation on a site. Vegetation can be completely or partially removed, or its composition altered, depending upon the intensity of the disturbance. Limited disturbance does not necessarily affect the investigator's ability to determine whether the plant community is or is not hydrophytic. However, if the vegetation on a site has been removed or made unidentifiable by a recent fire, flood, or other disturbance, then one or more of the following approaches may be used to determine whether the vegetation present before the disturbance was hydrophytic. Additional guidance can be found in Part IV, Section F (Atypical Situations) of the Corps Manual.

(1) Examine the vegetation on a nearby, undisturbed reference site having similar soils and hydrologic conditions. Assume that the same plant community would exist on the disturbed site in the absence of disturbance.

(2) Use offsite data sources such as aerial photography, NWI maps, and interviews with knowledgeable people to determine what plant community was present on the site before the disturbance.

(3) If the undisturbed vegetation condition cannot be determined, make the wetland determination based on indicators of hydric soil and wetland hydrology.

f. *Areas dominated exclusively by non-vascular plants*. In areas that lack vascular plants but are dominated by peat mosses (e.g., *Sphagnum* spp.), the vegetation should be considered to be hydrophytic if indicators of hydric soil and wetland hydrology are present, the landscape position is appropriate for wetlands, and hydrology has not been altered.

5. General Approaches to Problematic Hydrophytic Vegetation. The following general procedures are provided to identify hydrophytic vegetation in difficult situations not necessarily associated with specific vegetation types or management practices, including wetlands dominated by FACU, NI, NO, or unlisted species that are functioning as hydrophytes. The following recommended approaches should be applied only where indicators of hydric soil and wetland hydrology are present (or are absent due to disturbance or other problem situations) and the landscape position is appropriate to collect or concentrate water, but indicators of hydrophytic vegetation are not evident.

a. *FACU species that commonly dominate wetlands*. The following FACU species occur in and dominate many wetlands in the North-central and Northeast Region and may cause a wetland plant community to fail to meet any of the hydrophytic vegetation indicators described in Chapter 2: eastern hemlock (*Tsuga canadensis*), eastern white pine (*Pinus strobus*), red spruce (*Picea rubens*), pitch pine (*Pinus rigida*), Virginia creeper (*Parthenocissus quinquefolia*), springbeauty (*Claytonia virginica*), and the following non-native species: common buckthorn (*Rhamnus cathartica*), multiflora rose (*Rosa multiflora*), tartarian honeysuckle (*Lonicera tatarica*), and Morrow's honeysuckle (*L. morrowii*) (indicator statuses may vary by plant list region). If the potential wetland area lacks hydrophytic vegetation indicators due to the presence of one or more of the FACU species listed above, use the following procedure to make the hydrophytic vegetation determination:

(1) At each sampling point in the potential wetland, drop any FACU species listed above from the vegetation data, and compile the species list and coverage data for the remaining species in the community.

(2) Reevaluate the remaining vegetation using hydrophytic vegetation indicators 2 (Dominance Test) and/or 3 (Prevalence Index). If either indicator is met, then the vegetation is hydrophytic.

b. *Direct hydrologic observations.* Verify that the plant community occurs in an area subject to prolonged inundation or soil saturation during the growing season. This can be done by visiting the site at 2- to 3-day intervals during the portion of the growing season when surface water is most likely to be present or water tables are normally high. Hydrophytic vegetation is considered to be present, and the site is a wetland, if surface water is present and/or the water table is 12 in. (30 cm) or less from the surface for 14 or more consecutive days during the growing season during a period when antecedent precipitation has been normal or drier than normal. If necessary, microtopographic highs and lows should be evaluated separately. The normality of the current year's rainfall must be considered in interpreting field results, as well as the likelihood that wet conditions will occur on the site at least every other year (for more information, see the section on "Wetlands that Periodically Lack Indicators of Wetland Hydrology" in this chapter).

c. *Reference sites with known hydrology*. If indicators of hydric soil and wetland hydrology are present, the site may be considered to be a wetland if the landscape setting, topography, soils, and vegetation are substantially the same as those on nearby wetland reference areas whose hydrology is known. Hydrologic characteristics of wetland reference areas should be documented through long-term monitoring or by application of the procedure described in item *5b* above. Reference sites should be minimally disturbed and provide long-term access. Soils, vegetation, and hydrologic conditions should be thoroughly documented and the data kept on file in the district or field office.

d. *Technical literature.* Published and unpublished scientific literature may be used to support a decision to treat specific FACU species or species with no assigned indicator status (e.g., NI, NO, or unlisted) as hydrophytes or certain plant communities as hydrophytic. Preferably, this literature should discuss the species' natural distribution along the moisture gradient, its capabilities and adaptations for life in wetlands, wetland types in which it is typically found, or other wetland species with which it is commonly associated.

Problematic hydric soils

Description of the problem

Soils with faint or no indicators

Some soils that meet the hydric soil definition may not exhibit any of the indicators presented in Chapter 3. These problematic hydric soils exist for a number of reasons and their proper identification requires additional information, such as landscape position, presence or absence of restrictive soil layers, or information about hydrology. This section describes several soil situations in the Northcentral and Northeast Region that are considered to be hydric if additional requirements are met. In some cases, these hydric soils may appear to be non-hydric due to the color of the parent material from which the soils developed. In others, the lack of hydric soil indicators is due to conditions (e.g., red parent materials) that inhibit the development of redoximorphic features despite prolonged soil saturation and anoxia. In addition, recently developed wetlands may lack hydric soil indicators because insufficient time has passed for their development. Examples of problematic hydric soils in the region include, but are not limited to, the following.

1. **Sandy Soils.** The development of hydric soil indicators can be inhibited in some sandy soils due to low iron or manganese content and/or low organic-matter content. To help identify the hydric soil boundary, examine soils in obvious wetland and non-wetland locations to determine what features to look for in soil profiles near the boundary. Use caution in areas where soil disturbances, such as plowing, may have brought red or black soil material from below to create what appear to be redoximorphic features near the surface.
2. **Red Parent Materials.** Soils derived from red parent materials are a challenge for hydric soil identification because the red, iron-rich materials contain minerals that are resistant to weathering and chemical reduction under anaerobic conditions. This inhibits the formation of redoximorphic features and typical hydric soil morphology. These soils are found in scattered locations throughout the region in areas of Mesozoic geologic materials or alluvium derived from these formations, including the Great Lakes region and river valleys in Connecticut and Massachusetts. A transect sampling approach can be helpful in making a hydric soil determination in soils derived from red parent materials. This involves describing the soil profile in an obvious non-wetland location and an

obvious wetland location to identify particular soil features that are related to the wetness gradient. Relevant features may include a change in soil matrix chroma (e.g., from 4 to 3) or the presence of redox depletions or reddish-black manganese concentrations. Hydric soil indicators F8 (Redox Depressions), F12 (Iron-Manganese Masses), and F21 (Red Parent Material) may be useful in identifying hydric soils in areas with red parent materials.

3. **Dark Parent Materials.** These soils formed in dark-colored (gray and black) parent materials derived from carboniferous and phyllitic bedrock. They occur in the Narragansett Basin of Rhode Island, parts of southeastern and western Massachusetts, throughout Vermont, and in extreme western New Hampshire. The inherited soil colors commonly are low chroma and low value, making it difficult to assess soil wetness using conventional morphological indicators. Low-chroma colors, depleted matrices, and redox depletions typically are masked by the dark mineralogy. Some features may be observable under magnification (Stolt et al. 2001).
4. **Fluvial Deposits within Floodplains.** These soils commonly occur on vegetated bars within the active channel and above the bankfull level of rivers and streams. In some cases, these soils lack hydric soil indicators due to seasonal or annual deposition of new soil material, low iron or manganese content, and/or low organic-matter content. Redox concentrations can sometimes be found between soil stratifications in areas where organic matter gets buried, such as along the fringes of floodplains.
5. **Recently Developed Wetlands.** Recently developed wetlands include mitigation sites, wetland management areas (e.g., for waterfowl), other wetlands intentionally or unintentionally produced by human activities, and naturally occurring wetlands that have not been in place long enough to develop hydric soil indicators.
6. **Seasonally Ponded Soils.** Seasonally ponded, depressional wetlands occur throughout the region. Many are perched systems with water ponding above a restrictive soil layer, such as a hardpan or clay layer that is at or near the surface. Ponded depressions also occur in floodplains where receding floodwaters, precipitation, and local runoff are held above a slowly permeable soil layer. Some of these wetlands lack hydric soil indicators due to the limited saturation depth.
7. **Wet Soils with High-Chroma Subsoils.** Several problematic soil situations occur in the region that result in the formation and persistence of high-chroma, wet soils. For example, in the oak openings region of Ohio, Indiana, and Michigan, along the interface between LRRs L and M,

some wetlands lack hydric soil indicators due to high-chroma subsoils (often a chroma of 4 or more) beneath a surface layer that may or may not exhibit hydric soil indicators. These soils formed in sandy beach deposits that originated along ancient lake shores during the Pleistocene period. Surface soil textures are often fine sands, fine sandy loams, and loamy fine sands. Underlying dense glacial till slows the infiltration of snowmelt and spring rainfall, causing water to perch for long periods within the sandy deposits above. Wind erosion in the oak openings can also transport soil material and bury natural soil horizons.

In addition, along the shorelines of the Great Lakes within LRRs L and K, some wetlands lack hydric soil indicators due to the presence of high-chroma sands (often a chroma of 3 or more). These high-chroma, sandy soils occur at the landward edge of coastal marshes, in interdunal wetlands, and in dune-and-swale complexes. They do not meet a hydric soil indicator due to matrix chromas greater than 2. These soils often exhibit redox concentrations as pore linings and/or soft masses within 12 in. (30 cm) of the surface. In adjacent upland areas, redox concentrations are absent or are only observed at depth. It may be helpful to involve a soil scientist or wetland scientist familiar with these problem soils.

8. **Discharge Areas for Iron-Enriched Groundwater.** Discharge of iron-enriched groundwater occurs in many locations throughout the region. The seasonal input of iron from the groundwater produces soil chromas generally greater than 3 and as high as 6 below the surface layer(s). These soils are usually found in seepage areas in glacial till, such as in areas with converging slopes or near-surface stratigraphic discontinuities. They can also occur on foot or toe slopes associated with sandy parent materials. Investigators should look for redox concentrations and depletions in the layer with high chroma and a depleted matrix below the layer of iron concentration. Wetland hydrology indicator B5 (Iron Deposits) can help to identify the presence of this problem soil (Figure 63).

Soils with relict hydric soil indicators

Some soils in the region exhibit redoximorphic features and hydric soil indicators that formed in the recent or distant past when conditions may have been wetter than they are today. These features have persisted even though wetland hydrology may no longer be present. Examples include soils associated with abandoned river courses and areas adjacent to deeply incised stream channels. In addition, wetlands drained for agricultural



Figure 63. Red areas in this photograph are iron deposits on the soil surface that are a result of high iron concentrations in the groundwater.

purposes starting in the 1800s may contain persistent hydric soil features. Wetland soils drained during historic times are still considered to be hydric but may lack the hydrology to support wetlands. Relict hydric soil features may be difficult to distinguish from contemporary features. However, if indicators of hydrophytic vegetation and wetland hydrology are present, then hydric soil indicators can be assumed to be contemporary.

Non-hydric soils that may be misinterpreted as hydric

In well-drained and aerated soils, iron translocation is also a normal process. Infiltrating water from precipitation or snowmelt moves downward through the soil profile and, together with organic acids derived from the litter layer, leaches or washes iron from the mineral layers near the surface. The iron moves downward in solution and accumulates in lower layers. As the near-surface layers are continually leached, their colors become similar to those of redox depletions. The accumulation of iron in the lower horizons may result in colors similar to redox concentrations. This coloration is most pronounced in Spodosols.

Spodosols are a common soil order in the Northcentral and Northeast Region. They form in relatively acidic soil materials and can be either hydric or non-hydric. In Spodosols, organic carbon, iron, and aluminum

are leached from a layer near the soil surface. This layer, known as the E horizon, has a bleached light-gray appearance and consists of relatively clean particles of sand and silt. The materials leached from the E horizon are deposited lower in the soil in the spodic horizon (e.g., Bhs or Bs horizon). If sufficient iron has been leached and redeposited, the spodic horizon will have a strong reddish color. In some Spodosols, E-horizon and spodic-horizon colors can be confused with the redox depletions and concentrations produced under anaerobic soil conditions. Normally, E horizons and spodic horizons are present in the soil in relatively continuous horizontal bands. Chemical weathering in an aerated soil is accomplished by the downward movement of water; therefore, the layers or horizons are relatively parallel to the soil surface and consistent across the soil. Transitions are relatively abrupt between the organic-enriched surface, the leached E horizon, and the iron-enriched B horizon. Below the B horizon, the transition becomes more gradual as the red hue of the iron-enriched B horizon gradually changes to the yellower hue of the underlying C horizon. However, if E horizons are thin or there are extensive plant roots, they may be discontinuous. Tree throw can also mix and break the horizons of aerated upland soils, so care should be taken to examine all site characteristics before concluding that a soil is hydric.

Generally, non-hydric Spodosols occur in the more mountainous portions of the region where temperatures are cooler. They tend to have thin, white-colored E horizons and spodic horizons that are less than 1 in. (2.5 cm) thick and not cemented. Hydric Spodosols are generally sandy in texture, have thicker gray-colored E horizons, and cemented spodic horizons (ortstein) that are greater than 1 in. (2.5 cm) thick.

Procedure

Soils that are thought to meet the definition of a hydric soil but do not exhibit any of the indicators described in Chapter 3 can be identified by the following recommended procedure. This procedure should be used only where indicators of hydrophytic vegetation and wetland hydrology are present (or are absent due to disturbance or other problem situations), but indicators of hydric soil are not evident.

1. Verify that one or more indicators of hydrophytic vegetation are present or that vegetation is problematic or has been altered (e.g., by tillage or other land alteration). If so, proceed to step 2.

2. Verify that at least one primary or two secondary indicators of wetland hydrology are present or that indicators are absent due to disturbance or other factors. If so, proceed to step 3. If indicators of hydrophytic vegetation and/or wetland hydrology are absent, then the area is probably non-wetland and no further analysis is required.
3. Thoroughly describe and document the soil profile and landscape setting. Verify that the area is in a landscape position that is likely to collect or concentrate water. If the landscape setting is appropriate, proceed to step 4. Appropriate settings include the following.

    a. Concave surface (e.g., depression or swale)
    b. Active floodplain or low terrace
    c. Level or nearly level area (e.g., 0- to 3-percent slope)
    d. Toe slope (Figure 6) or an area of convergent slopes (Figure 5)
    e. Fringe of another wetland or water body
    f. Area with a restrictive soil layer or aquitard within 24 in. (60 cm) of the surface
    g. Area where groundwater discharges (e.g., a seep)
    h. Other (explain in field notes why this area is likely to be inundated or saturated for long periods)

4. Use one or more of the following approaches to determine whether the soil is hydric. In the remarks section of the data form or in the delineation report, explain why it is believed that the soil lacks any of the NTCHS hydric soil indicators described in Chapter 3 and why it is believed that the soil meets the definition of a hydric soil.

    a. Determine whether one or more of the following indicators of problematic hydric soils is present. See the descriptions of each indicator given in Chapter 3. If one or more indicators are present, then the soil is hydric.

        (1) 2 cm Muck (A10) (applicable to LRR K, L, and MLRA 149B of LRR S)
        (2) Coast Prairie Redox (A16) (applicable to LRR K, L, and R)
        (3) 5 cm Mucky Peat or Peat (S3) (applicable to LRR K, L, and R)
        (4) Dark Surface (S7) (applicable to LRR K, L, and M)
        (5) Polyvalue Below Surface (S8) (applicable to LRR K and L)
        (6) Thin Dark Surface (S9) (applicable to LRR K and L)
        (7) Iron-Manganese Masses (F12) (applicable to LRR K, L, and R)

(8) Piedmont Floodplain Soils (F19) (applicable to MLRA 149B of LRR S)
(9) Mesic Spodic (TA6) (applicable to MLRAs 144A and 145 of LRR R and MLRA 149B of LRR S)
(10) Red Parent Material (F21) (applicable throughout the Northcentral and Northeast Region in areas containing soils derived from red parent materials)
(11) Very Shallow Dark Surface (TF12) (applicable throughout the Northcentral and Northeast Region)

b. Determine whether one or more of the following problematic soil situations is present. If present, consider the soil to be hydric.

(1) Sandy Soils
(2) Red Parent Materials
(3) Dark Parent Materials
(4) Fluvial Deposits within Floodplains
(5) Recently Developed Wetlands
(6) Seasonally Ponded Soils
(7) Wet Soils with High-Chroma Subsoils
(8) Discharge Areas for Iron-Enriched Groundwater
(9) Other (in field notes, describe the problematic soil situation and explain why it is believed that the soil meets the hydric soil definition)

c. Soils that have been saturated for long periods and have become chemically reduced may change color when exposed to air due to the rapid oxidation of ferrous iron (Fe^{2+}) to Fe^{3+} (i.e., a reduced matrix) (Figures 64 and 65). If the soil contains sufficient iron, this can result in an observable color change, especially in hue or chroma. The soil is hydric if a mineral layer 4 in. (10 cm) or more thick starting within 12 in. (30 cm) of the soil surface that has a matrix value of 4 or more and chroma of 2 or less becomes redder by one or more pages in hue and/or increases one or more in chroma when exposed to air within 30 minutes (Vepraskas 1992).

Care must be taken to obtain an accurate color of the soil sample immediately upon excavation. The colors should be observed closely and examined again after several minutes. Do not allow the sample to become dry. Dry soils will usually have a different color than wet or

moist soils. As always, do not attempt to determine colors while wearing sunglasses or tinted lenses. Colors must be determined in the field under natural light and not under artificial light.

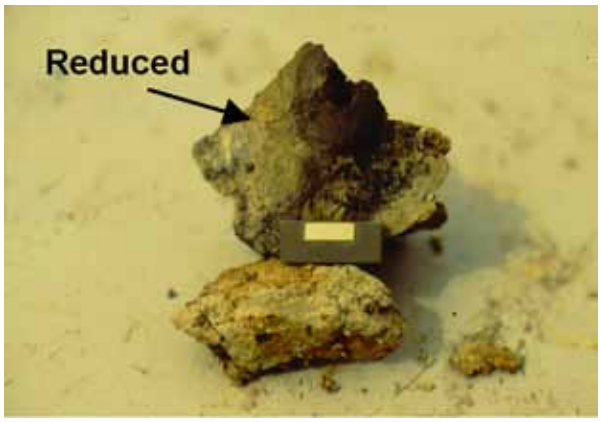


Figure 64. This soil exhibits colors associated with reducing conditions. Scale is 1 cm.

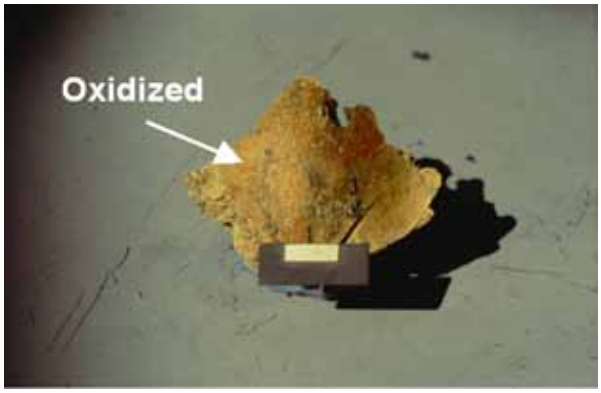


Figure 65. The same soil as in Figure 63 after exposure to the air and oxidation has occurred.

d. If the soil is saturated at the time of sampling, alpha, alpha-dipyridyl reagent can be used in the following procedure to determine if reduced (ferrous) iron is present. If ferrous iron is present as described below, then the soil is hydric.

   Alpha, alpha-dipyridyl is a reagent that reacts with reduced iron. In some cases, it can be used to provide evidence that a soil is hydric when it lacks other hydric soil indicators. The soil is likely to be hydric if application of alpha, alpha-dipyridyl to mineral soil material in at least 60 percent of a layer at least 4 in. (10 cm) thick within a depth of 12 in. (30 cm) of the soil surface results in a positive reaction within 30 seconds evidenced by a pink or red coloration to the reagent during the growing season.

Using a dropper, apply a small amount of reagent to a freshly broken ped face to avoid any chance of a false positive test due to iron contamination from digging tools. Look closely at the treated soil for evidence of color change. If in doubt, apply the reagent to a sample of known upland soil and compare the reaction to the sample of interest. A positive reaction will not occur in soils that lack iron and may not occur in soils with high pH. The lack of a positive reaction to the reagent does not preclude the presence of a hydric soil. Specific information about the use of alpha, alpha-dipyridyl can be found in NRCS Hydric Soils Technical Note 8 (http://soils.usda.gov/use/hydric/ntchs/tech_notes/index.html).

e. Using gauge data, water-table monitoring data, or repeated direct hydrologic observations, determine whether the soil is ponded or flooded, or the water table is 12 in. (30 cm) or less from the surface, for 14 or more consecutive days during the growing season in most years (at least 5 years in 10, or 50 percent or higher probability) (U.S. Army Corps of Engineers 2005). If so, then the soil is hydric. Furthermore, any soil that meets the NTCHS hydric soil technical standard (NRCS Hydric Soils Technical Note 11, http://soils.usda.gov/use/hydric/ntchs/tech_notes/index.html) is hydric.

Wetlands that periodically lack indicators of wetland hydrology

Description of the problem

Wetlands are areas that are flooded or ponded, or have soils that are saturated with water, for long periods during the growing season in most years. If the site is visited during a time of normal precipitation amounts and it is inundated or the water table is near the surface, then the wetland hydrology determination is straight forward. During the dry season, however, surface water recedes from wetland margins, water tables drop, and many wetlands dry out completely. Superimposed on this seasonal cycle is a long-term pattern of multi-year droughts alternating with years of higher-than-average rainfall. Wetlands in general are inundated or saturated at least 5 years in 10 (50 percent or higher probability) over a long-term record. However, some wetlands in the Northcentral and Northeast Region do not become inundated or saturated in some years and, during drought cycles or prolonged dry conditions, may not inundate or saturate for several years in a row.

Wetland hydrology determinations are based on indicators, many of which were designed to be used during dry periods when the direct observation of surface water or a shallow water table is not possible. However, some wetlands may lack any of the listed hydrology indicators, particularly during the dry season or in a dry year. Examples in the region include vernal pools and potholes, floodplain wetlands, flatwoods, interdunal swales, wet prairies, sedge meadows, and other wet meadows. The evaluation of wetland hydrology requires special care on any site where indicators of hydrophytic vegetation and hydric soil are present but hydrology indicators appear to be absent. Among other factors, this evaluation should consider the timing of the site visit in relation to normal seasonal and annual hydrologic variability, and whether the amount of rainfall prior to the site visit has been normal. This section describes a number of approaches that can be used to determine whether wetland hydrology is present on sites where indicators of hydrophytic vegetation and hydric soil are present but hydrology indicators may be lacking due to normal variations in rainfall or runoff, human activities that destroy hydrology indicators, and other factors.

Procedure

1. Verify that indicators of hydrophytic vegetation and hydric soil are present, or are absent due to disturbance or other problem situations. If so, proceed to step 2.
2. Verify that the site is in a landscape position that is likely to collect or concentrate water. If the landscape setting is appropriate, proceed to step 3. Appropriate settings are listed below.

    a. Concave surface (e.g., depression or swale)
    b. Active floodplain or low terrace
    c. Level or nearly level area (e.g., 0- to 3-percent slope)
    d. Toe slope (Figure 6) or an area of convergent slopes (Figure 5)
    e. Fringe of another wetland or water body
    f. Area with a restrictive soil layer or aquitard within 24 in. (60 cm) of the surface
    g. Area where groundwater discharges (e.g., a seep)
    h. Other (explain in field notes why this area is likely to be inundated or saturated for long periods)

3. Use one or more of the following approaches to determine whether wetland hydrology is present and the site is a wetland. In the remarks section

of the data form or in the delineation report, explain the rationale for concluding that wetland hydrology is present even though indicators of wetland hydrology described in Chapter 4 were not observed.

a. *Site visits during the dry season*. Determine whether the site visit occurred during the normal annual "dry season." The dry season, as used in this supplement, is the period of the year when soil moisture is normally being depleted and water tables are falling to low levels in response to decreased precipitation and/or increased evapotranspiration, usually during late spring and summer. It also includes the beginning of the recovery period in late summer or fall. The Web-Based Water-Budget Interactive Modeling Program (WebWIMP) is one source for approximate dates of wet and dry seasons for any terrestrial location based on average monthly precipitation and estimated evapotranspiration (http://climate.geog.udel.edu/~wimp/). In general, the dry season in a typical year is indicated when potential evapotranspiration exceeds precipitation (indicated by negative values of DIFF in the WebWIMP output), resulting in drawdown of soil moisture storage (negative values of DST) and/or a moisture deficit (positive values of DEF, also called the unmet atmospheric demand for moisture). Actual dates for the dry season vary by locale and year.

   In many wetlands, direct observation of flooding, ponding, or a shallow water table would be unexpected during the dry season. Wetland hydrology indicators, if present, would most likely be limited to indirect evidence, such as water marks, drift deposits, or surface cracks. In some situations, hydrology indicators may be absent during the dry season. If the site visit occurred during the dry season on a site that contains hydric soils and hydrophytic vegetation and no significant hydrologic manipulation (e.g., no dams, levees, water diversions, land grading, etc., and the site is not within the zone of influence of any ditches or subsurface drains), then consider the site to be a wetland. If necessary, revisit the site during the normal wet season and check again for the presence or absence of wetland hydrology indicators, or use one or more of the following evaluation methods.

b. *Periods with below-normal rainfall*. Determine whether the amount of rainfall that occurred in the 2 to 3 months preceding the site visit was normal, above normal, or below normal based on the normal range reported in WETS tables. WETS tables are provided by the

NRCS National Water and Climate Center (http://www.wcc.nrcs.usda.gov/climate/wetlands.html) and are calculated from long-term (30-year) weather records gathered at National Weather Service meteorological stations. To determine whether precipitation was normal prior to the site visit, actual rainfall in the current month and previous 2 to 3 months should be compared with the normal ranges for each month given in the WETS table (USDA Natural Resources Conservation Service 1997, Sprecher and Warne 2000). The lower and upper limits of the normal range are indicated by the columns labeled "30% chance will have less than" and "30% chance will have more than" in the WETS table. The USDA Natural Resources Conservation Service (1997, Section 650.1903) also gives a procedure that can be used to weight the information from each month and determine whether the entire period was normal, wet, or dry.

When precipitation has been below normal, wetlands may not flood, pond, or develop shallow water tables even during the typical wet portion of the growing season and may not exhibit other indicators of wetland hydrology. Therefore, if precipitation was below normal prior to the site visit, and the site contains hydric soils and hydrophytic vegetation and no significant hydrologic manipulation (e.g., no dams, levees, water diversions, land grading, etc., and the site is not within the zone of influence of any ditches or subsurface drains), then consider the site to be a wetland. If necessary, revisit the site during a period of normal rainfall and check again for hydrology indicators, or use one or more of the other evaluation methods described in this section.

c. *Drought years*. Determine whether the area has been subject to drought. Drought periods can be identified by comparing annual rainfall totals with the normal range of annual rainfall given in WETS tables or by examining trends in drought indices, such as the Palmer Drought Severity Index (PDSI) (Sprecher and Warne 2000). PDSI takes into account not only precipitation but also temperature, which affects evapotranspiration, and soil moisture conditions. The index is usually calculated on a monthly basis for major climatic divisions within each state. Therefore, the information is not site-specific. PDSI ranges potentially between –6 and +6 with negative values indicating dry periods and positive values indicating wet periods. An index of -1.0 indicates mild drought, –2.0 indicates moderate drought, -3.0 indicates severe drought, and –4.0 indicates extreme drought.

Time-series plots of PDSI values by month or year are available from the National Climatic Data Center at (http://www.ncdc.noaa.gov/oa/climate/onlineprod/drought/xmgr.html#ds). If wetland hydrology indicators appear to be absent on a site that has hydrophytic vegetation and hydric soils, no significant hydrologic manipulation (e.g., no dams, levees, water diversions, land grading, etc., and the site is not within the zone of influence of any ditches or subsurface drains), and the region has been affected by drought, then consider the site to be a wetland. If necessary, revisit the site during a normal rainfall year and check again for wetland hydrology indicators, or use one or more of the other methods described in this section.

d. *Reference sites*. If indicators of hydric soil and hydrophytic vegetation are present on a site that lacks wetland hydrology indicators, the site may be considered to be a wetland if the landscape setting, topography, soils, and vegetation are substantially the same as those on nearby wetland reference areas with known hydrology. Hydrology of wetland reference areas should be documented through long-term monitoring (see item *g* below) or by application of the procedure described in item *5b* on page 132 (Direct Hydrologic Observations) of the procedure for Problematic Hydrophytic Vegetation in this chapter. Reference sites should be minimally disturbed and provide long-term access. Soils, vegetation, and hydrologic conditions should be thoroughly documented and the data kept on file in the District or field office.

e. *Hydrology tools*. The "Hydrology Tools" (USDA Natural Resources Conservation Service 1997) is a collection of methods that can be used to determine whether wetland hydrology is present on a potential wetland site that lacks indicators due to disturbance or other reasons, particularly on lands used for agriculture. Generally they require additional information, such as aerial photographs or stream-gauge data, or involve hydrologic modeling and approximation techniques. These methods are not intended to overrule an indicator-based wetland determination on a site that is not disturbed or problematic. A hydrologist may be needed to help select and carry out the proper analysis. The seven hydrology tools are used to:

(1) Analyze stream and lake gauge data

(2) Estimate runoff volumes and determine duration and frequency of ponding in depressional areas, based on precipitation and temperature data, soil characteristics, land cover, and other inputs
(3) Evaluate the frequency of wetness signatures on repeated aerial photography (see item *f* below for additional information)
(4) Model water-table fluctuations in fields with parallel drainage systems using the DRAINMOD model
(5) Estimate the "scope and effect" of ditches or subsurface drain lines
(6) Use NRCS state drainage guides to estimate the effectiveness of agricultural drainage systems
(7) Analyze data from groundwater monitoring wells (see item *g* below for additional information)

f. *Evaluating multiple years of aerial photography*. Each year, the Farm Service Agency (FSA) takes low-level aerial photographs in agricultural areas to monitor the acreages planted in various crops for USDA programs. NRCS has developed an off-site procedure that uses these photos, or repeated aerial photography from other sources, to make wetland hydrology determinations (USDA Natural Resources Conservation Service 1997, Section 650.1903). The method is intended for use on agricultural lands where human activity has altered or destroyed other wetland indicators. However, the same approach may be useful in other environments.

The procedure uses five or more years of growing-season photography and evaluates each photo for wetness signatures that are listed in "wetland mapping conventions" developed by NRCS state offices. Wetland mapping conventions can be found in the electronic Field Office Technical Guide (eFOTG) for each state (http://www.nrcs.usda.gov/technical/efotg/). From the national web site, choose the appropriate state, then select any county (the state's wetland mapping conventions are the same in every county). Wetland mapping conventions are listed among the references in Section I of the eFOTG. However, not all states have wetland mapping conventions.

Wetness signatures for a particular state may include surface water, saturated soils, flooded or drowned-out crops, stressed crops due to wetness, differences in vegetation patterns due to different planting dates, inclusion of wet areas into set-aside programs, unharvested crops, isolated areas that are not farmed with the rest of the field,

patches of greener vegetation during dry periods, and other evidence of wet conditions (see Part 513.30 of USDA Natural Resources Conservation Service 1994). For each photo, the procedure described in item *b* above is used to determine whether the amount of rainfall in the 2 to 3 months prior to the date of the photo was normal, below normal, or above normal. Only photos taken in normal rainfall years, or an equal number of wetter-than-normal and drier-than-normal years, are used in the analysis. If wetness signatures are observed on photos in more than half of the years included in the analysis, then wetland hydrology is present. Data forms that may be used to document the wetland hydrology determination are given in section 650.1903 of USDA Natural Resources Conservation Service (1997).

g. *Long-term hydrologic monitoring.* On sites where the hydrology has been manipulated by man (e.g., with ditches, subsurface drains, dams, levees, water diversions, land grading) or where natural events (e.g., downcutting of streams) have altered conditions such that hydrology indicators may be missing or misleading, direct monitoring of surface and groundwater may be needed to determine the presence or absence of wetland hydrology. The U. S. Army Corps of Engineers (2005) provides minimum standards for the design, construction, and installation of water-table monitoring wells, and for the collection and interpretation of groundwater monitoring data, in cases where direct hydrologic measurements are needed to determine whether wetlands are present on highly disturbed or problematic sites. This standard calls for 14 or more consecutive days of flooding, ponding, or a water table 12 in. (30 cm) or less below the soil surface during the growing season at a minimum frequency of 5 years in 10 (50 percent or higher probability), unless a different standard has been established for a particular geographic area or wetland type. A disturbed or problematic site that meets this standard has wetland hydrology. This standard is not intended (1) to overrule an indicator-based wetland determination on a site that is not disturbed or problematic, or (2) to test or validate existing or proposed wetland indicators.

Wetland/non-wetland mosaics

Description of the problem

In this supplement, “mosaic” refers to a landscape where wetland and non-wetland components are too closely associated to be easily delineated or

mapped separately. These areas often have complex microtopography, with repeated small changes in elevation occurring over short distances. Tops of ridges and hummocks are often non-wetland but are interspersed throughout a wetland matrix having clearly hydrophytic vegetation, hydric soils, and wetland hydrology. Potential examples of wetland/non-wetland mosaics in the Northcentral and Northeast Region include ridge-and-swale topography on floodplains; dune-and-swale systems near the Great Lakes and Atlantic coast; current and former flatwoods, such as those on the Lake Superior clay plain in northeastern Minnesota and northern Wisconsin; areas that exhibit bedding from agricultural or silvicultural operations; areas containing numerous vernal pools; and areas where wind-thrown trees have created pit-and-mound or cradle/knoll topography.

Wetland components of a mosaic are often not difficult to identify. The problem for the wetland delineator is that microtopographic features are too small and intermingled, and there are too many such features per acre, to delineate and map them accurately. Instead, the following sampling approach can be used to estimate the percentage of wetland in the mosaic. From this, the number of acres of wetland on the site can be calculated, if needed.

Procedure

First, identify and flag all contiguous areas of either wetland or non-wetland on the site that are large enough to be delineated and mapped separately. The remaining area should be mapped as "wetland/non-wetland mosaic" and the approximate percentage of wetland within the area determined by the following procedure.

1. Establish one or more continuous line transects across the mosaic area, as needed. Measure the total length of each transect. A convenient method is to stretch a measuring tape along the transect and leave it in place while sampling. If the site is shaped appropriately and multiple transects are used, they should be arranged in parallel with each transect starting from a random point along one edge of the site. However, other arrangements of transects may be needed for oddly shaped sites.
2. Use separate data forms for the swales or troughs and for the ridges or hummocks. Sampling of vegetation, soil, and hydrology should follow the general procedures described in the Corps Manual and this supplement. Plot sizes and shapes for vegetation sampling must be adjusted to fit the microtopographic features on the site. Plots intended to sample the

troughs should not overlap adjacent hummocks, and vice versa. Only one or two data forms are required for each microtopographic position, and do not need to be repeated for similar features or plant communities.

3. Identify every wetland boundary in every trough or swale encountered along each transect. Each boundary location may be marked with a pin flag or simply recorded as a distance along the stretched tape.
4. Determine the total distance along each transect that is occupied by wetlands and non-wetlands until the entire length of the line has been accounted for. Sum these distances across transects, if needed. Determine the percentage of wetland in the wetland/non-wetland mosaic by the following formula.

$$\%\ wetland = \frac{Total\ wetland\ distance\ along\ all\ transects}{Total\ length\ of\ all\ transects} \times 100$$

An alternative approach involves point-intercept sampling at fixed intervals along transects across the area designated as wetland/non-wetland mosaic. This method avoids the need to identify wetland boundaries in each swale, and can be carried out by pacing rather than stretching a measuring tape across the site. The investigator uses a compass or other means to follow the selected transect line. At a fixed number of paces (e.g., every two steps) the wetland status of that point is determined by observing indicators of hydrophytic vegetation, hydric soil, and wetland hydrology. Again, a completed data form is not required at every point but at least one representative swale and hummock should be documented with completed forms. After all transects have been sampled, the result is a number of wetland sampling points and a number of non-wetland points. Estimate the percentage of wetland in the wetland/non-wetland mosaic by the following formula:

$$\%\ wetland = \frac{Number\ of\ wetland\ points\ along\ all\ transects}{Total\ number\ of\ points\ sampled\ along\ all\ transects} \times 100$$

If high-quality aerial photography is available for the site, a third approach to estimating the percentage of wetland in a wetland/non-wetland mosaic is to use a dot grid, planimeter, or geographic information system (GIS) to determine the percentage of ridges (non-wetlands) and swales (wetlands) through photo interpretation of topography and vegetation patterns. This technique requires onsite verification that most ridges qualify as non-wetlands and most swales qualify as wetlands.

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Appendix A: Glossary

This glossary is intended to supplement those given in the Corps Manual and other available sources. See the following publications for terms not listed here:

- Corps Manual (Environmental Laboratory 1987) (http://el.erdc.usace.army.mil/wetlands/pdfs/wlman87.pdf).
- Field Indicators of Hydric Soils in the United States (USDA Natural Resources Conservation Service 2010) (http://soils.usda.gov/use/hydric/).
- National Soil Survey Handbook, Part 629 (USDA Natural Resources Conservation Service 2005) (ftp://ftp-fc.sc.egov.usda.gov/NSSC/Soil_Survey_Handbook/629_glossary.pdf).

Absolute cover. In vegetation sampling, the percentage of the ground surface that is covered by the aerial portions (leaves and stems) of a plant species when viewed from above. Due to overlapping plant canopies, the sum of absolute cover values for all species in a community or stratum may exceed 100 percent. In contrast, "relative cover" is the absolute cover of a species divided by the total coverage of all species in that stratum, expressed as a percent. Relative cover cannot be used to calculate the prevalence index.

Aquitard. A layer of soil or rock that retards the downward flow of water and is capable of perching water above it. For the purposes of this supplement, the term aquitard also includes the term aquiclude, which is a soil or rock layer that is incapable of transmitting significant quantities of water under ordinary hydraulic gradients.

Contrast. The color difference between a redox concentration and the dominant matrix color. Differences are classified as faint, distinct, or prominent and are defined in the glossary of USDA Natural Resources Conservation Service (2010) and illustrated in Table A1.

Table A1. Tabular key for contrast determinations using Munsell notation.

Hues are the same (Δ h = 0)			Hues differ by 2 pages (Δ h = 2)		
Δ Value	Δ Chroma	Contrast	Δ Value	Δ Chroma	Contrast
0	≤1	Faint	0	0	Faint
0	2	Distinct	0	1	Distinct
0	3	Distinct	0	≥2	Prominent
0	≥4	Prominent	1	≤1	Distinct
1	≤1	Faint	1	≥2	Prominent
1	2	Distinct	≥2	---	Prominent
1	3	Distinct			
1	≥4	Prominent			
≤2	≤1	Faint			
≤2	2	Distinct			
≤2	3	Distinct			
≤2	≥4	Prominent			
3	≤1	Distinct			
3	2	Distinct			
3	3	Distinct			
3	≥4	Prominent			
≥4	---	Prominent			
Hues differ by 1 page (Δ h = 1)			Hues differ by 3 or more pages (Δ h ≥ 3)		
Δ Value	Δ Chroma	Contrast	Δ Value	Δ Chroma	Contrast
0	≤1	Faint	Color contrast is prominent, except for low chroma and value.		Prominent
0	2	Distinct			
0	≥3	Prominent			
1	≤1	Faint			
1	2	Distinct			
1	≥3	Prominent			
2	≤1	Distinct			
2	2	Distinct			
2	≥3	Prominent			
≥3	---	Prominent			

Note: If both colors have values of ≤3 and chromas of ≤2, the color contrast is Faint (regardless of the difference in hue).

Adapted from USDA Natural Resources Conservation Service (2002)

Depleted matrix. The volume of a soil horizon or subhorizon from which iron has been removed or transformed by processes of reduction and translocation to create colors of low chroma and high value. A, E, and calcic horizons may have low chromas and high values and may therefore be mistaken for a depleted matrix. However, they are excluded from the concept of depleted matrix unless common or many, distinct or prominent redox concentrations as soft masses or pore linings are present. In some places the depleted matrix may change color upon exposure to air (reduced matrix); this phenomenon is included in the concept of depleted matrix. The following combinations of value and chroma identify a depleted matrix:

- Matrix value of 5 or more and chroma of 1, with or without redox concentrations occurring as soft masses and/or pore linings, or
- Matrix value of 6 or more and chroma of 2 or 1, with or without redox concentrations occurring as soft masses and/or pore linings, or
- Matrix value of 4 or 5 and chroma of 2, with 2 percent or more distinct or prominent redox concentrations occurring as soft masses and/or pore linings, or
- Matrix value of 4 and chroma of 1, with 2 percent or more distinct or prominent redox concentrations occurring as soft masses and/or pore linings (USDA Natural Resources Conservation Service 2010).

Common (2 to less than 20 percent) to many (20 percent or more) redox concentrations (USDA Natural Resources Conservation Service 2002) are required in soils with matrix colors of 4/1, 4/2, and 5/2 (Figure A1). Redox concentrations include iron and manganese masses and pore linings (Vepraskas 1992). See “contrast” in this glossary for the definitions of “distinct” and “prominent.”

Diameter at breast height (DBH). A standard method of expressing the diameter of the trunk or bole measured at 1.37 meters (4.5 ft) above the ground. On sloping ground, measurements should be taken from the uphill side of the trunk.

Diapause. A period during which growth or development is suspended and physiological activity is diminished, as in certain aquatic invertebrates in response to drying of temporary wetlands.

Distinct. See Contrast.

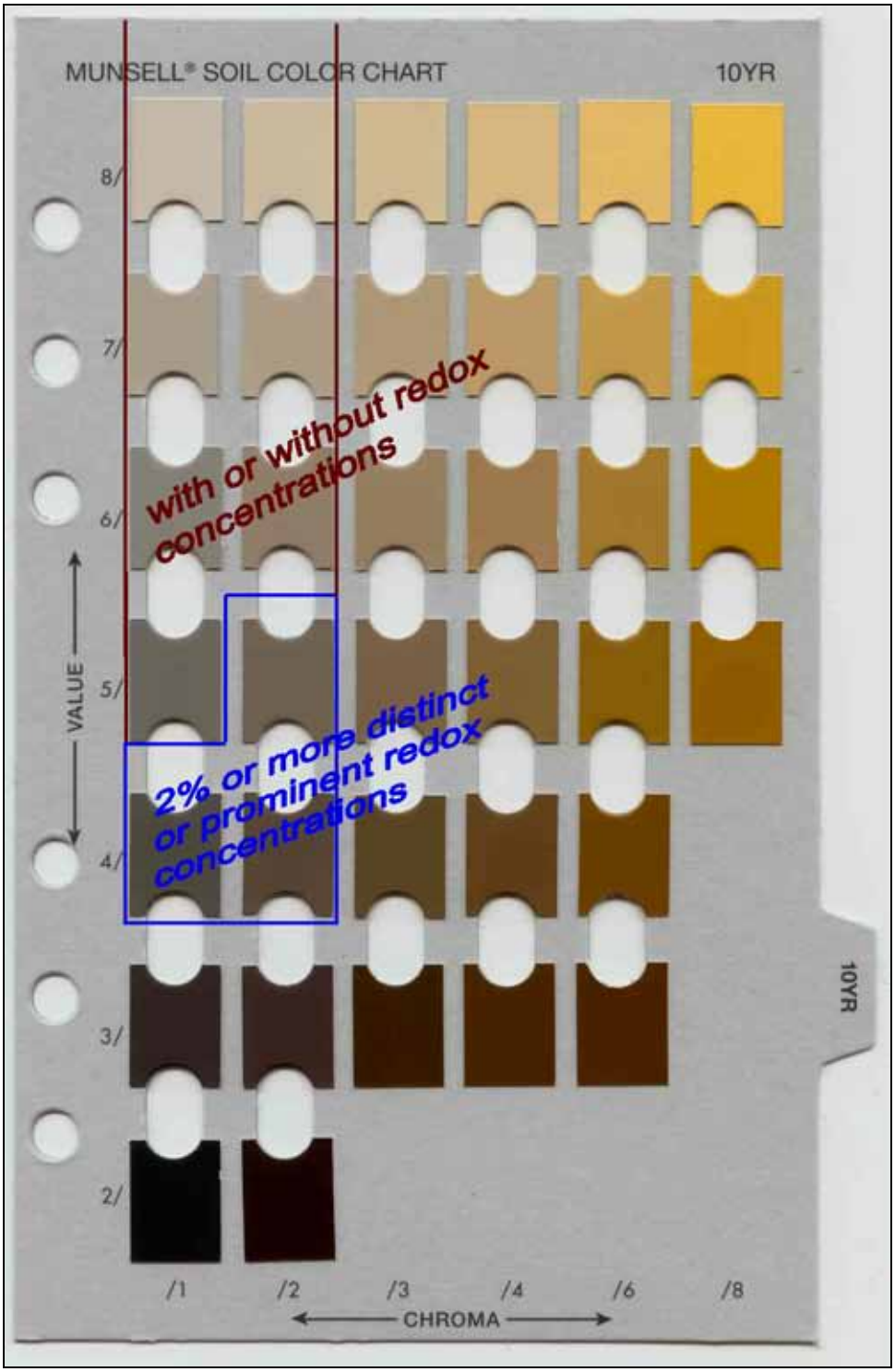


Figure A1. Illustration of values and chromas that require 2 percent or more distinct or prominent redox concentrations and those that do not, for hue 10YR, to meet the definition of a depleted matrix. *Due to inaccurate color reproduction, do not use this page to determine soil colors in the field.* Background image from the Munsell Soil Color Charts reprinted courtesy of Munsell Color Services Lab, a part of X-Rite, Inc. (Gretag/Macbeth 2000).

Episaturation. Condition in which the soil is saturated with water at or near the surface, but also has one or more unsaturated layers below the saturated zone. The zone of saturation is perched on top of a relatively impermeable layer.

Flark-and-strang topography. Microtopographic relief consisting of flarks (linear pools or swales) and strangs or strings (low ridges) oriented perpendicular to the direction of water flow in patterned fens, bogs, and other peatlands (Foster and King 1984).

Fragmental soil material. Soil material that consists of 90 percent or more rock fragments; less than 10 percent of the soil consists of particles 2 mm or smaller (USDA Natural Resources Conservation Service 2010).

Gleyed matrix. A gleyed matrix has one of the following combinations of hue, value, and chroma and the soil is not glauconitic (Figure A2):

- 10Y, 5GY, 10GY, 10G, 5BG, 10BG, 5B, 10B, or 5PB with value of 4 or more and chroma of 1; or
- 5G with value of 4 or more and chroma of 1 or 2; or
- N with value of 4 or more (USDA Natural Resources Conservation Service 2010).

Growing season. In the Northcentral and Northeast Region, growing season dates are determined through onsite observations of the following indicators of biological activity in a given year: (1) above-ground growth and development of vascular plants and/or (2) soil temperature (see Chapter 4 for details). If onsite data gathering is not practical, growing season dates may be approximated by using WETS tables available from the NRCS National Water and Climate Center to determine the median dates of 28 °F (−2.2 °C) air temperatures in spring and fall based on long-term records gathered at the nearest appropriate National Weather Service meteorological station.

High pH. pH of 7.9 or higher. Includes Moderately Alkaline, Strongly Alkaline, and Very Strongly Alkaline (USDA Natural Resources Conservation Service 2002).

Hummock. A low mound, ridge, or microtopographic high. In wet areas, plants growing on hummocks may avoid some of the deleterious effects of inundation or shallow water tables.

Layer(s). A soil horizon, subhorizon, or combination of contiguous horizons or subhorizons sharing at least one property referred to in the indicators.



Figure A2. For hydric soil determinations, a gleyed matrix has the hues and chroma identified in this illustration with a value of 4 or more. *Due to inaccurate color reproduction, do not use this page to determine soil colors in the field.* Background image from the Munsell Soil Color Charts reprinted courtesy of Munsell Color Services Lab, a part of X-Rite, Inc. (Gretag/Macbeth 2000).

Nodules and concretions. Irregularly shaped, firm to extremely firm accumulations of iron and manganese oxides. When broken open, nodules have uniform internal structure whereas concretions have concentric layers (Vepraskas 1992).

Ped. A unit of soil structure, such as a block, column, granule, plate, or prism, formed by natural processes.

Prominent. See Contrast.

Red parent material. Parent material with a natural inherent reddish color attributable to the presence of iron oxides occurring as coatings on and occluded within the mineral grains. Soils that formed in red parent material have conditions that greatly retard the development and extent of the redoximorphic features that normally occur under prolonged aquic conditions. Most commonly, the material consists of dark red, consolidated Mesozoic or Paleozoic sedimentary rocks, such as shale, siltstone, and sandstone, or alluvial materials derived from such rocks. Assistance from a local soil scientist may be needed to determine where red parent material occurs.

Reduced matrix. Soil matrix that has a low chroma in situ due to presence of reduced iron, but whose color changes in hue or chroma when exposed to air as Fe^{2+} is oxidized to Fe^{3+} (Vepraskas 1992).

Saturation. For wetland delineation purposes, a soil layer is saturated if virtually all pores between soil particles are filled with water (National Research Council 1995, Vepraskas and Sprecher 1997). This definition includes part of the capillary fringe above the water table (i.e., the tension-saturated zone) in which soil water content is approximately equal to that below the water table (Freeze and Cherry 1979).

Tussock. A plant growth form, generally in grasses or sedges, in which plants grow in tufts or clumps bound together by roots and elevated above the substrate.

Within. When referring to specific hydric soil indicator depth requirements, “within” means not beyond in depth. “Within a depth of 15 cm,” for example indicates that the depth is less than or equal to 15 cm.

Appendix B: Point-Intercept Sampling Procedure for Determining Hydrophytic Vegetation

The following procedure for point-intercept sampling is an alternative to plot-based sampling methods to estimate the abundance of plant species in a community. The approach may be used with the approval of the appropriate Corps of Engineers District to evaluate vegetation as part of a wetland delineation. Advantages of point-intercept sampling include better quantification of plant species abundance and reduced bias compared with visual estimates of cover. The method is useful in communities with high species diversity, and in areas where vegetation is patchy or heterogeneous, making it difficult to identify representative locations for plot sampling. Disadvantages include the increased time required for sampling and the need for vegetation units large enough to permit the establishment of one or more transect lines within them. The approach also assumes that soil and hydrologic conditions are uniform across the area where transects are located. In particular, transects should not cross the wetland boundary. Point-intercept sampling is generally used with a transect-based prevalence index (see below) to determine whether vegetation is hydrophytic.

In point-intercept sampling, plant occurrence is determined at points located at fixed intervals along one or more transects established in random locations within the plant community or vegetation unit. If a transect is being used to sample the vegetation near a wetland boundary, the transect should be placed parallel to the boundary and should not cross either the wetland boundary or into other communities. Usually a measuring tape is laid on the ground and used for the transect line. Transect length depends upon the size and complexity of the plant community and may range from 100 to 300 ft (30 to 90 m) or more. Plant occurrence data are collected at fixed intervals along the line, for example every 2 ft (0.6 m). At each interval, a “hit” on a species is recorded if a vertical line at that point would intercept the stem or foliage of that species. Only one “hit” is recorded for a species at a point even if the same species would be intercepted more than once at that point. Vertical intercepts can be determined using a long pin or rod protruding into and through the

various vegetation layers, a sighting device (e.g., for the canopy), or an imaginary vertical line. The total number of "hits" for each species along the transect is then determined. The result is a list of species and their frequencies of occurrence along the line (Mueller-Dombois and Ellenberg 1974; Tiner 1999). Species are then categorized by wetland indicator status (i.e., OBL, FACW, FAC, FACU, or UPL), the total number of hits determined within each category, and the data used to calculate a transect-based prevalence index. The formula is similar to that given in Chapter 2 for the plot-based prevalence index (see Indicator 3), except that frequencies are used in place of cover estimates. The community is hydrophytic if the prevalence index is 3.0 or less. To be valid, more than 80 percent of "hits" on the transect must be of species that have been identified correctly and placed in an indicator category.

The transect-based prevalence index is calculated using the following formula:

$$PI = \frac{F_{OBL} + 2F_{FACW} + 3F_{FAC} + 4F_{FACU} + 5F_{UPL}}{F_{OBL} + F_{FACW} + F_{FAC} + F_{FACU} + F_{UPL}}$$

where:

PI = Prevalence index;
F_{OBL} = Frequency of obligate (OBL) plant species;
F_{FACW} = Frequency of facultative wetland (FACW) plant species;
F_{FAC} = Frequency of facultative (FAC) plant species;
F_{FACU} = Frequency of facultative upland (FACU) plant species;
F_{UPL} = Frequency of upland (UPL) plant species.

Appendix C: Data Form

WETLAND DETERMINATION DATA FORM – Northcentral and Northeast Region

Project/Site: _____ City/County: _____ Sampling Date: _____

Applicant/Owner: _____ State: _____ Sampling Point: _____

Investigator(s): _____ Section, Township, Range: _____

Landform (hillslope, terrace, etc.): _____ Local relief (concave, convex, none): _____ Slope (%): _____

Subregion (LRR or MLRA): _____ Lat: _____ Long: _____ Datum: _____

Soil Map Unit Name: _____ NWI classification: _____

Are climatic / hydrologic conditions on the site typical for this time of year? Yes _____ No _____ (If no, explain in Remarks.)

Are Vegetation _____, Soil _____, or Hydrology _____ significantly disturbed? Are "Normal Circumstances" present? Yes _____ No _____

Are Vegetation _____, Soil _____, or Hydrology _____ naturally problematic? (If needed, explain any answers in Remarks.)

SUMMARY OF FINDINGS – Attach site map showing sampling point locations, transects, important features, etc.

Hydrophytic Vegetation Present? Yes _____ No Hydric Soil Present? Yes _____ No Wetland Hydrology Present? Yes _____ No	**Is the Sampled Area within a Wetland? Yes _____ No** If yes, optional Wetland Site ID: _____

Remarks: (Explain alternative procedures here or in a separate report.)

HYDROLOGY

Wetland Hydrology Indicators:

Primary Indicators (minimum of one is required; check all that apply)

- ___ Surface Water (A1)
- ___ High Water Table (A2)
- ___ Saturation (A3)
- ___ Water Marks (B1)
- ___ Sediment Deposits (B2)
- ___ Drift Deposits (B3)
- ___ Algal Mat or Crust (B4)
- ___ Iron Deposits (B5)
- ___ Inundation Visible on Aerial Imagery (B7)
- ___ Sparsely Vegetated Concave Surface (B8)
- ___ Water-Stained Leaves (B9)
- ___ Aquatic Fauna (B13)
- ___ Marl Deposits (B15)
- ___ Hydrogen Sulfide Odor (C1)
- ___ Oxidized Rhizospheres on Living Roots (C3)
- ___ Presence of Reduced Iron (C4)
- ___ Recent Iron Reduction in Tilled Soils (C6)
- ___ Thin Muck Surface (C7)
- ___ Other (Explain in Remarks)

Secondary Indicators (minimum of two required)

- ___ Surface Soil Cracks (B6)
- ___ Drainage Patterns (B10)
- ___ Moss Trim Lines (B16)
- ___ Dry-Season Water Table (C2)
- ___ Crayfish Burrows (C8)
- ___ Saturation Visible on Aerial Imagery (C9)
- ___ Stunted or Stressed Plants (D1)
- ___ Geomorphic Position (D2)
- ___ Shallow Aquitard (D3)
- ___ Microtopographic Relief (D4)
- ___ FAC-Neutral Test (D5)

Field Observations:

Surface Water Present? Yes _____ No _____ Depth (inches):

Water Table Present? Yes _____ No _____ Depth (inches):

Saturation Present? (includes capillary fringe) Yes _____ No _____ Depth (inches):

Wetland Hydrology Present? Yes _____ No

Describe Recorded Data (stream gauge, monitoring well, aerial photos, previous inspections), if available:

Remarks:

VEGETATION – Use scientific names of plants. Sampling Point: _____

Tree Stratum (Plot size: _____)	Absolute % Cover	Dominant Species?	Indicator Status
1.			
2.			
3.			
4.			
5.			
6.			
7.			
	_____ = Total Cover		
Sapling/Shrub Stratum (Plot size: _____)			
1.			
2.			
3.			
4.			
5.			
6.			
7.			
	_____ = Total Cover		
Herb Stratum (Plot size: _____)			
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			
	_____ = Total Cover		
Woody Vine Stratum (Plot size: _____)			
1.			
2.			
3.			
4.			
	_____ = Total Cover		

Dominance Test worksheet:

Number of Dominant Species That Are OBL, FACW, or FAC: _____ (A)

Total Number of Dominant Species Across All Strata: _____ (B)

Percent of Dominant Species That Are OBL, FACW, or FAC: _____ (A/B)

Prevalence Index worksheet:

Total % Cover of:	Multiply by:
OBL species _____	x 1 = _____
FACW species _____	x 2 = _____
FAC species _____	x 3 = _____
FACU species _____	x 4 = _____
UPL species _____	x 5 = _____
Column Totals: _____ (A)	_____ (B)

Prevalence Index = B/A =

Hydrophytic Vegetation Indicators:

___ 1 - Rapid Test for Hydrophytic Vegetation

___ 2 - Dominance Test is >50%

___ 3 - Prevalence Index is ≤3.0[1]

___ 4 - Morphological Adaptations[1] (Provide supporting data in Remarks or on a separate sheet)

___ Problematic Hydrophytic Vegetation[1] (Explain)

[1]Indicators of hydric soil and wetland hydrology must be present, unless disturbed or problematic.

Definitions of Vegetation Strata:

Tree – Woody plants 3 in. (7.6 cm) or more in diameter at breast height (DBH), regardless of height.

Sapling/shrub – Woody plants less than 3 in. DBH and greater than or equal to 3.28 ft (1 m) tall.

Herb – All herbaceous (non-woody) plants, regardless of size, and woody plants less than 3.28 ft tall.

Woody vines – All woody vines greater than 3.28 ft in height.

Hydrophytic Vegetation Present? **Yes** _____ **No**

Remarks: (Include photo numbers here or on a separate sheet.)

SOIL

Sampling Point: _____

Profile Description: (Describe to the depth needed to document the indicator or confirm the absence of indicators.)

Depth (inches)	Matrix Color (moist)	%	Redox Features Color (moist)	%	Type[1]	Loc[2]	Texture	Remarks

[1]Type: C=Concentration, D=Depletion, RM=Reduced Matrix, MS=Masked Sand Grains. [2]Location: PL=Pore Lining, M=Matrix.

Hydric Soil Indicators:

- ___ Histosol (A1)
- ___ Histic Epipedon (A2)
- ___ Black Histic (A3)
- ___ Hydrogen Sulfide (A4)
- ___ Stratified Layers (A5)
- ___ Depleted Below Dark Surface (A11)
- ___ Thick Dark Surface (A12)
- ___ Sandy Mucky Mineral (S1)
- ___ Sandy Gleyed Matrix (S4)
- ___ Sandy Redox (S5)
- ___ Stripped Matrix (S6)
- ___ Dark Surface (S7) (**LRR R, MLRA 149B**)
- ___ Polyvalue Below Surface (S8) (**LRR R, MLRA 149B**)
- ___ Thin Dark Surface (S9) (**LRR R, MLRA 149B**)
- ___ Loamy Mucky Mineral (F1) (**LRR K, L**)
- ___ Loamy Gleyed Matrix (F2)
- ___ Depleted Matrix (F3)
- ___ Redox Dark Surface (F6)
- ___ Depleted Dark Surface (F7)
- ___ Redox Depressions (F8)

Indicators for Problematic Hydric Soils[3]:

- ___ 2 cm Muck (A10) (**LRR K, L, MLRA 149B**)
- ___ Coast Prairie Redox (A16) (**LRR K, L, R**)
- ___ 5 cm Mucky Peat or Peat (S3) (**LRR K, L, R**)
- ___ Dark Surface (S7) (**LRR K, L, M**)
- ___ Polyvalue Below Surface (S8) (**LRR K, L**)
- ___ Thin Dark Surface (S9) (**LRR K, L**)
- ___ Iron-Manganese Masses (F12) (**LRR K, L, R**)
- ___ Piedmont Floodplain Soils (F19) (**MLRA 149B**)
- ___ Mesic Spodic (TA6) (**MLRA 144A, 145, 149B**)
- ___ Red Parent Material (F21)
- ___ Very Shallow Dark Surface (TF12)
- ___ Other (Explain in Remarks)

[3]Indicators of hydrophytic vegetation and wetland hydrology must be present, unless disturbed or problematic.

Restrictive Layer (if observed):

Type:_____

Depth (inches):_____

Hydric Soil Present? Yes _____ No _____

Remarks:

REPORT DOCUMENTATION PAGE

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This document is one of a series of Regional Supplements to the Corps of Engineers Wetland Delineation Manual, which provides technical guidance and procedures for identifying and delineating wetlands that may be subject to regulatory jurisdiction under Section 404 of the Clean Water Act or Section 10 of the Rivers and Harbors Act. The development of Regional Supplements is part of a nation-wide effort to address regional wetland characteristics and improve the accuracy and efficiency of wetland-delineation procedures. This supplement is applicable to the Northcentral and Northeast Region, which consists of all or portions of 15 states: Connecticut, Illinois, Indiana, Maine, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, and Wisconsin.

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Wetlands

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Appendix D – USACE ER 1110-1-1807

Omitted due to file sharing protections by USACE.

Appendix E – Sampling Strategies and Statistics Training Materials for Part 201 Cleanup (MDEQ 2002)



Sampling Strategies and Statistics Training Materials

for

Part 201 Cleanup Criteria

Michigan Department of Environmental Quality
Remediation and Redevelopment Division
www.michigan.gov/deq
John Engler, Governor
Russell J. Harding, Director

2002

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Introduction

INTRODUCTION

INTRODUCTION

Sampling Strategies and Statistics Training Materials for Part 201 Cleanup Criteria (S^3TM) was developed to help staff of the Michigan Department of Environmental Quality (MDEQ) by providing recommendations on:

1. sampling of environmental media for various sampling objectives under Part 201, Environmental Remediation, of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended (NREPA), and

2. determining when it is appropriate to use statistics and which statistical methods to use for comparing data to Part 201 cleanup criteria.

Appropriate sampling strategies differ based on the sampling objectives (e.g, *FACILITY* characterization, verification of remediation, comparison to criteria, or waste characterization), the variability of hazardous substances in the media to be sampled, knowledge about the distribution of hazardous substances on a property, and costs. The S^3TM provides recommendations on sampling strategies based on these considerations. Biased and statistical sampling strategies are presented and discussed.

After sampling has been completed, the degree to which statistics can be used and the selection of statistical method(s) will vary depending on the exposure pathway, land-use category, and type of determination being made (i.e., *FACILITY* determination, remedial action, and verification of remediation and closure). These training materials do not reflect an increased expectation by the department for the use of statistics, but rather are provided to guide decision-making when statistics are used or *PROPOSED* to help assure it is done properly (terms in capitalized italicized font are defined in the tabbed section titled, "Acronyms / Glossary").

Specifically, the S^3TM will help staff answer three basic questions for making cleanup determinations or know when to seek assistance if statistics are being used to assess compliance with applicable criteria:

1. Is a statistical analysis appropriate?
2. What is the appropriate data set to statistically derive a *REPRESENTATIVE CONCENTRATION* for comparison to cleanup criteria?
3. What is the appropriate statistical method to use for comparison to the cleanup criteria?

1. <u>Is a statistical analysis appropriate?</u>

Statistical Guidesheets have been developed to describe the extent to which statistical analysis of data may be relied upon to evaluate each exposure pathway and condition. At the top of each Statistical Guidesheet is an Applicability of Statistics Section which summarizes the primary factors to consider for that exposure pathway or condition. "**YES**," "Generally Not Practical (**GNP**)" or "**NO**" appear in a box to the right of the Applicability of Statistics heading to indicate the degree to which statistical analysis is appropriate. The Statistical Guidesheets are lettered and numbered to correspond with the Criteria Application Guidesheets presented in the Cleanup Criteria Training Material (CCTM).

Statistical Guidesheets categorized as "**YES**" indicate that use of statistics may be appropriate for the exposure pathway/condition and that sufficient data are likely to be available to calculate a *REPRESENTATIVE CONCENTRATION* for comparison to cleanup criteria. Statistical Guidesheets designated as "**GNP**" indicate that statistical applications may be appropriate but that data are not likely to be available and/or the complexities of the exposure pathway/condition make it difficult to derive a *REPRESENTATIVE CONCENTRATION* for comparison to cleanup criteria. Conditions for which no generic criteria have been developed (e.g., polluted soil runoff to surface water), are also designated as **GNP**. Finally, the exposure pathway categorized as "**NO**" means that statistical analysis is not allowed due to an administrative rule requirement. This is true only for the drinking water pathway for which Administrative Rule 709(3) requires that criteria be met at every point in the affected aquifer.

For quick reference, the CCTM general reference table titled, "Conditions to Evaluate in Assessing Compliance with Part 201 Cleanup Criteria," has been expanded to identify the applicability of statistics for each condition to evaluate. This table can be found in the tabbed section titled, "Applicability of Statistics." Remember that in cases where criteria are not applicable, it is not necessary to conduct a statistical analysis of *FACILITY* data.

2. What is the appropriate data set to statistically derive a *REPRESENTATIVE CONCENTRATION* for comparison to cleanup criteria?

Selecting the proper data set for a statistical analysis, if a statistical analysis is appropriate for the exposure pathway or condition, is an important step given the manner in which sampling data are typically obtained at sites. Section 2 of the Statistical Guidesheets addresses Selection of Data for Statistical Analysis.

FACILITY characterization is a necessary first step before an appropriate data set can be identified for statistical comparison to cleanup criteria. Adequate knowledge of contaminant distribution and the presence of *HOT SPOTS* are essential due to assumptions underlying the statistical methods recommended for comparing site data to cleanup criteria (i.e., 95% upper confidence limits (UCLs) for the mean concentration). Adherence to these assumptions is necessary if an accurate statistical conclusion is to be drawn. Once defined, *HOT SPOTS* should not be included in a statistical analysis for comparison to most criteria. *HOT SPOTS* must be addressed separately. These concepts are discussed in more detail in Section 2.4.1 of the tabbed section titled, "Sampling Strategies."

Once the nature and extent of contamination has been defined, it is necessary to identify and/or obtain data that will allow for appropriate comparison to criteria. The statistical methods described in this document require independence of the data (i.e., the data were obtained through *RANDOM* sampling). However, data gathered from *FACILITY* investigations may not be suitable for statistical comparison to cleanup criteria. Samples collected for the purpose of characterizing a *FACILITY* are typically biased, based on factors such as historical information, previous sampling, disposal practices, visual impacts, and aerial photos.

There are two primary considerations in determining if data sets are adequate. First, data sets must be obtained from locations that represent the exposure pathway or condition and the relevant land-use category. For many of the exposure pathways *EXPOSURE UNITS* are defined to describe the area over which a person may be exposed to hazardous substances and data required for each *EXPOSURE UNIT*. Second, if statistics are used, data sets must contain a sufficient number of *RANDOMLY* located sample results to adequately represent hazardous substance concentrations and allow for proper statistical analysis and development of *REPRESENTATIVE CONCENTRATIONS*. Therefore, additional sampling will often be required to

support statistical analyses after the nature and extent of contamination has been defined. Although *RANDOM* samples are preferred for deriving a *REPRESENTATIVE CONCENTRATION*, previous sample results may be used on a *FACILITY*-specific basis. See further discussion of this issue in Section 2.4.2 of the tabbed section titled, "Sampling Strategies."

The appropriate data set for statistical analysis also depends on the size and variability of hazardous substance concentrations in the *EXPOSURE UNIT*. The size of the *EXPOSURE UNIT* varies between different exposure pathways and the land-use category being considered. Generally, only data from one *EXPOSURE UNIT* may be used in each statistical analysis for comparison to cleanup criteria.

Section 2 of the Statistical Guidesheets also provides information related to unique aspects of the exposure pathway/condition that affect which data may be included in a statistical analysis for comparison to criteria. For example, only groundwater data from *GSI MONITORING WELLS* within the *AVERAGING AREA* may be used for statistical comparison to chronic mixing zone-based groundwater surface water interface (GSI) criteria.

3. What is the appropriate statistical method to use for comparison to the cleanup criteria?

Proper evaluation of data sets to assess compliance for an exposure pathway and/or condition is an important objective of the S^3TM. Once the applicability of statistics has been established and an appropriate data set identified, it is necessary to select the appropriate statistical method(s) for comparing those data to Part 201 criteria.

For characterizing human exposure potential to hazardous substances, the Environmental Protection Agency (EPA) recommends that a 95% UCL for the mean be used to estimate a reasonable maximum exposure (RME) concentration for Superfund risk assessments. The MDEQ also recommends use of a 95% UCL for the mean to compare *FACILITY* data to Part 201 criteria.

Use of a 95% UCL for the mean to compare *FACILITY* data to Part 201 criteria corresponds to a baseline assumption that the mean hazardous substance concentration is at or above its respective criterion unless the data provide sufficient evidence to conclude otherwise. This baseline assumption is consistent with EPA's recommendations in the context of federal cleanup programs (e.g., Superfund and Resource Conservation and Recovery Act (RCRA) Corrective Action).

Various methods are available for calculating UCLs for the mean concentration. Selection of the appropriate method requires an evaluation of the assumptions underlying each method. One of these assumptions is the statistical distribution of the data set (i.e., normal, lognormal, or neither). Consequently, each data set must be evaluated for the best-fitting statistical distribution. Chapter 1 of the tabbed section titled, "Statistical Methods" provides several techniques to accomplish this task. As described in Chapter 1, these techniques should be used in combination to best evaluate the statistical distribution.

Chapter 2 of the tabbed section titled, "Statistical Methods" provides techniques for identifying whether suspect data points are statistical outliers. Recommendations for treatment of outliers, once identified, are also provided in Chapter 2.

Methods for calculating UCLs for the mean concentration are provided in Chapter 3 of the tabbed section titled, "Statistical Methods."

Relationship to the Part 201 CCTM

This S^3TM builds on the framework of the CCTM of January 1998 by providing guidance for statistically analyzing sample data to assess compliance with Part 201 cleanup criteria. Part 201 Section 20a(14) states: "the department shall approve the use of probabilistic or statistical methods or other scientific methods of evaluating environmental data when determining compliance with a pertinent cleanup criterion if the methods are determined by the department to be reliable, scientifically valid, and best represent actual site conditions and exposure potential." Since many divisions of the MDEQ utilize Part 201 criteria, the S^3TM will be useful for this purpose across the MDEQ.

Statistical Considerations Related to *BACKGROUND*

Under Part 201, *BACKGROUND* becomes the Part 201 criterion when the *BACKGROUND* concentration for a hazardous substance is greater than its corresponding risk-based criterion. In this case, *FACILITY* data may be compared to *BACKGROUND* concentrations instead. Chapter 4 of the tabbed section titled, "Statistical Methods" provides recommended statistical methods for this purpose. Recommended methods vary depending on: 1) type of *BACKGROUND* being considered (i.e., *STATEWIDE DEFAULT BACKGROUND*, *REGIONAL BACKGROUND*, or *FACILITY-SPECIFIC BACKGROUND*) and 2) whether a statistical analysis of *FACILITY* data is appropriate for comparison to risk-based criteria. Because statistical distribution and presence of outliers remain important considerations for selection of appropriate method(s) to compare *FACILITY* data to *BACKGROUND* data, Chapter 4 refers back to Chapters 1 and 2 for these considerations.

Relationship to the "Verification of Soil Remediation" (VSR) Guidance Document (MDNR 1994; Revision 1)

Topics addressed in the VSR have been incorporated into the S^3TM and updated as necessary to reflect regulatory requirements under Part 201. The VSR was written in the context of the Michigan Environmental Response Act (MERA), 1982 PA 307, as amended, prior to the 1995 amendments. Consequently, recommendations in the VSR do not address concepts addressed by Part 201 such as evaluation of exposure pathways. Statistical methods presented in the VSR have also been updated to reflect more state-of-the-art recommendations in the statistical analysis of environmental data.

The VSR provided sampling recommendations for both verifying remediation and characterizing wastes. The VSR also presented some statistical methods for evaluating verification or characterization data. Sampling strategies for verifying remediation are described in Sections 1.3 and 2.3 of the tabbed section titled, "Sampling Strategies." Statistical methods for comparing data to criteria are provided the tabbed section titled, "Statistical Methods." Waste characterization is addressed in the tabbed section titled, "Waste Characterization."

Professional Judgment

The S^3TM supplements the tools available to aid in decision-making and do not replace or diminish the use of other appropriate tools such as professional judgment. For example, professional judgment may be used to determine that a *FACILITY* has been adequately characterized based primarily on biased sampling. Professional judgment may also be used to evaluate the significance of environmental data in a manner that does not require a statistical

analysis of *FACILITY* data. If it is determined that data are not representative of a quantity of hazardous substance that could result in an unacceptable risk, it may be appropriate to draw a conclusion without using statistics, even if one or more data points are greater than the cleanup criteria.

Cleanup criteria that are based on projections of the fate and transport of a hazardous substance from one media to another (e.g., groundwater volatilization to indoor air), and the screening levels (i.e., flammability and explosivity, acute inhalation) are good examples of pathways where the quantity of hazardous substance that is present can be considered in applying the screening levels or criteria. If a single data point exceeds an acute inhalation screening level, but that data point is representative of only a small area of groundwater, the sample is from considerable depth below ground surface, and the concentration is not substantially greater than the screening level, it may be concluded that there is no need for response activity to address this situation. This is a conclusion based on professional judgment, not on a statistical evaluation.

The S^3TM is aimed primarily at sampling (i.e., recommended approaches to data gathering) and the use of statistics in decision-making under Part 201. Some decisions, however, will be determined on a qualitative basis (e.g., source control), since cleanup criteria are not available for all conditions.

Self-Implementation

Part 201 Section 14(2) states: "A person may undertake response activity without prior approval by the department unless that response activity is being done pursuant to an administrative order or agreement or judicial decree which requires prior department approval. Any such action shall not relieve any person of liability for further response activity as may be required by the department." A self-implemented response activity using statistics to support determinations must be documented in a manner that fully and clearly addresses the three questions outlined in this Introduction.

Waste Characterization

Characterization of wastes for the purpose of disposal must often be addressed at Part 201 *FACILITIES*. Waste characterization is regulated under Part 111, Hazardous Waste Management and Part 115, Solid Waste Management, of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended (NREPA). Because there is a great deal of overlap in sampling strategies and statistical methods that can be used to compare data to criteria under Parts 201, 111 and 115, considerations related to waste characterization are also provided in this document. The tabbed section titled, "Waste Characterization" provides most of the recommendations related to waste characterization. Many of these considerations have also been incorporated in the tabbed sections titled, "Sampling Strategies" and "Statistical Methods."

APPLICABILITY OF STATISTICS TO EACH CONDITION TO EVALUATE

APPLICABILITY OF STATISTICS TO EACH CONDITION TO EVALUATE
General Reference Table

	CONDITION	REFERENCE GUIDESHEET(S)	APPLICABILITY OF STATISTICS
SOURCES:			
1	Abandoned substances not yet dispersed & free phase liquids	A 7, 20	GNP Pathway Dependent
RISKS DUE TO GROUNDWATER CONTAMINATION:			
2	Drinking water usage	**1**, 2, 7	NO
3	Dermal exposures such as by utility workers	**6**, 7, 8, 9	GNP
4	Indoor air hazards (chronic/systemic)	**4**, 5, 7, 8, 9	GNP
5	Hazards to surface waters	**3**, 7	YES / NO
RISKS DUE TO SOIL CONTAMINATION:			
6	Hazards due to direct contact (ingestion, dermal)	10, **19**, 20, 27, 28, 29	YES
7	Ambient air inhalation hazards	10, **15**, **16**, **17**, **18**, 20, 23, 24, 25, 26	YES
8	Indoor air inhalation hazards	10, **14**, 20, 22	GNP
9	Injury to drinking water use of aquifer	10, **11**, 20, 21	GNP
10	Risk from contact (utility work) with groundwater	10, **13**, 20	GNP
11	Causes groundwater to be hazardous to surface water	10, **12**, 20	GNP
12	Polluted soil runoff to surface water	B, 10, 20	GNP
RISKS DUE TO CONTAMINATION OF SURFACE WATER SEDIMENTS:			
13	Aquatic flora/fauna/food chain hazards/aesthetics	C	GNP
OTHER RISKS:			
14	Acute toxic impacts/physical hazards	D, 8, 9	GNP
15	Terrestrial flora/fauna/food chain hazards/aesthetics	E	GNP
16	Asbestos containing materials	F	Pathway Dependent

Note: **Bold** guidesheet references indicate generic residential cleanup criteria.

APPLICABILITY OF STATISTICS

YES: Use of statistics may be appropriate for this pathway/condition and sufficient data are likely to be available to calculate a *REPRESENTATIVE CONCENTRATION* for comparison to cleanup criteria.

NO: Use of statistics is not allowed for this pathway/condition due to an administrative rule requirement. This is true only for the drinking water pathway in which administrative rule 709(3) requires that criteria be met at every point in the affected aquifer.

GNP: Use of statistics may be appropriate for this pathway/condition but data are not likely to be available and/or the complexities of the exposure pathway/condition make it difficult to derive a *REPRESENTATIVE CONCENTRATION* for comparison to cleanup criteria. Conditions for which no generic criteria have been developed (e.g., polluted soil runoff to surface water) are also designated as “GNP.”

STATISTICAL ANALYSIS WORKSHEETS

Tab 3.0

Worksheets

STATISTICAL ANALYSIS REVIEW WORKSHEET

GENERAL INFORMATION

SITE/PROJECT: _____

☐ **RAP** ☐ **Final IR** ☐ **Due Care** ☐ **Other** _____

Submittal Being Evaluated: _____

Release Area: _____

Substance evaluated: _____

Pathway/Land use: _____

Current criterion value: _____

Applicability of Statistics: ☐ **Yes** ☐ **No*** ☐ **GNP***

*** DEQ Action Taken:** _____

Conclusion of Submittal For This Substance:

Representative Concentration: _____

Statistical Method Used: ☐ 95% UCL for the mean ☐ Other _____

ADEQUACY OF CHARACTERIZATION

1) Nature and extent of contaminant distribution determined? ☐ Yes ☐ No

Comments: _____

2) Is there evidence "Hot Spots" or potential "Hot Spots" remain present? ☐ Yes ☐ No ☐ Unknown

Comments: _____

Characterization adequate to proceed with statistical analysis? ☐ Yes ☐ No*

*DEQ Action Taken:

REVIEW OF DATA SET

CHARACTERISTICS	SUBMITTAL	GUIDESHEET RECOMMENDATION	RECOMMENDATION SATISFIED?
Size of Area Evaluated (Exposure Unit / Averaging Area)	_____ ☐ Acres ☐ Sq. Ft. ☐ _____	_____ Acres / sq.ft. guidesheet number _____ or, matches areas used for mixing zone determination.	☐ Yes ☐ No Comments:_____
Number of Observations		9 minimum per exposure unit per stats guidesheet	☐ Yes ☐ No Comments:_____
Basis For Sample Points		Random, per stats guidesheet	☐ Yes ☐ No ☐ Unknown Comments:_____
Detection Limit		_____ Per op memo #6	☐ Yes ☐ No Comments:_____
Percent Non-Detects		<50% for use of std. methods per statistical methods section (alt. methods to be proposed if >50%.)	☐ Yes ☐ No Comments:_____

REVIEW OF STATISTICAL ANALYSIS

1) STATISTICAL DISTRIBUTION OF DATA SET

Submittal

Distribution: ☐ Normal ☐ Lognormal ☐ Neither

Formal Test: ☐ Shapiro-Wilk Test ☐ Shapiro-Francia Test

Graphical Technique: ☐ Probability Plots ☐ Box Plots

Summary Statistics: ☐ Coefficient of Variation ☐ Coefficient of Skewness

DEQ Review

Distribution: ☐ Normal ☐ Lognormal ☐ Neither

Formal Test: ☐ Shapiro-Wilk Test ☐ Shapiro-Francia Test

Graphical Technique ☐ Probability Plots ☐ Box Plots

Summary Statistics: ☐ Coefficient of Variation ☐ Coefficient of Skewness

Attach notes / worksheets for above method(s) used. Analysis must include a formal test, a probability plot and summary statistics.

2) OUTLIER EVALUATION

Submittal

Was data set evaluated for outliers?

☐ No
☐ Yes

How were outliers identified?
(Check all that apply)

☐ Graphically

☐ Probability Plot ☐ Box Plot ☐ Other_____

☐ Formal tests (Assumed distribution: _____)

☐ Grubbs' Test ☐ Dixon's Test

☐ Rosner's Test ☐ Other_____

CONCLUSIONS

☐ Value(s) not outliers(s)
☐ Value(s) confirmed as outliers

Treatment of outlier value(s)

☐ Included in statistical analysis
☐ Excluded from statistical analysis

Justification (for either): _____

_____

_____

DEQ Review

☐ No potential outliers in data set based upon qualitative review and / or plots
(Proceed to #3)

☐ Potential outliers evident in dataset

Is data set either normal or lognormal?

☐ Yes, outlier(s) tested by:

☐ Grubbs' Test ☐ Dixon's Test
☐ Rosner's Test ☐ Other _____

☐ No, outlier(s) tested by:

☐ Iterative Approach
☐ Other _____

CONCLUSIONS

☐ Value(s) not outliers(s) (Proceed to #3)
☐ Value(s) confirmed as outlier(s)

Treatment of outlier(s)

☐ Outlier value investigated and found to be erroneous because:

_____

_____

Correct value =_____ **or** ☐ Not discernible
(Return to #1) (Exclude value and document, proceed to #3)

☐ Outlier value apparently accurate, but extreme for population and not from a Hot Spot (Proceed to #3)

☐ Outlier value apparently accurate and may represent a Hot Spot (Return to Adequacy of Characterization)

3) CALCULATION OF REPRESENTATIVE CONCENTRATION

Submittal

Statistical method used:

☐ Student's t (for normally distributed data sets)

☐ Land's Method (lognormally distributed data)

☐ Other _____

Representative Concentration:

DEQ Review

Statistical method used

☐ Student's t (for normally distributed data sets)

☐ Land's Method (lognormally distributed data)

☐ Other formulas as proposed and discussed with DEQ Statistician

Representative Concentration:

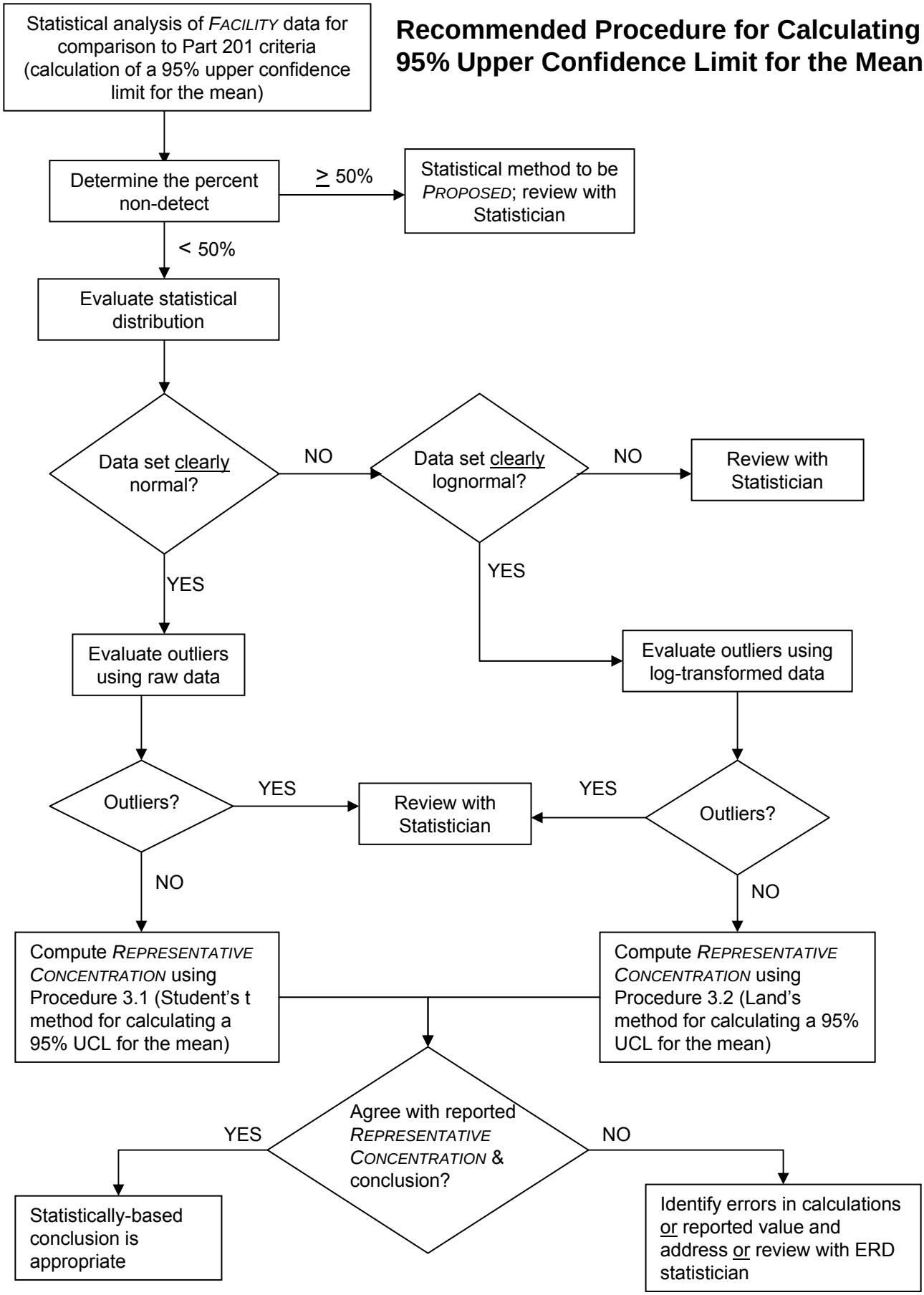
CONCLUSIONS OF REVIEW

☐ **Review supports conclusion of the submittal for the representative concentration of this substance at this location OR**
☐ **Review finds conclusion of the submittal for the representative concentration of this substance IS NOT appropriate because:**

AND Statistical Analysis ☐ DOES ☐ DOES NOT provide evidence of compliance with this criterion for this substance at this location.

Staff Reviewer: _____ Review Date: _____

Recommended Procedure for Calculating a 95% Upper Confidence Limit for the Mean



SAMPLING STRATEGIES

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INTRODUCTION

Environmental sampling is often conducted to support a variety of interrelated data objectives. When developing a sampling plan, these objectives require careful consideration if useful data are to be obtained. The objectives for sampling addressed in this tabbed section include:

- identifying and characterizing *RELEASE* areas;
- verifying remediation of *RELEASE* areas;
- comparing *FACILITY* data to Part 201 cleanup criteria, either on a point-by-point basis or using statistics to derive a *REPRESENTATIVE CONCENTRATION*;
- characterizing wastes; and
- establishing *BACKGROUND* concentrations.

Systematic selection of the appropriate sampling strategy is an important first step in satisfying the environmental sampling objectives listed above. Two basic sampling strategies or designs are commonly used for environmental sampling: biased (judgmental) or *RANDOMIZED* (statistical). Further discussion of these strategies occurs in Chapters 1 and 2, respectively.

The DEQ recognizes that sampling to meet these environmental management objectives is a challenging and complex undertaking. This is due in part to the dynamic nature of environmental media (air, water, soil, sediments). Data from environmental sampling are static, representing only a single location and point in time. The complexity and dynamic nature of environmental media is often overlooked in sample planning, collection and cleanup decisions based on static sample data. Thoughtful consideration of the following questions will result in a more effective and efficient sampling strategy.

- Why sample?
  - What is the goal or purpose (data objective) of sampling (e.g., characterization, release area identification, verification of remediation, demonstration of compliance using statistics, demonstration of due care)?
  - Will sample results be used to draw conclusions about human health risks through various exposure pathways, natural resource damage, biological impacts?
- What to sample?
  - Sample media: air, water, soil, sediments, waste materials
  - Hazardous substances: *FACILITY*-specific constituents of concern, organic constituents and their breakdown products, inorganic constituents, metals
- Where to sample?
  - Locations based on biased versus *RANDOM* sampling strategies
  - Vertical sampling components

- When to sample?
  - Are there seasonal variations?
  - Time or history of *RELEASE* – when did the *RELEASE* occur?
  - What are the dynamics of the system(s)?

- How to sample?
  - Discrete grab sample versus continuous sampling
  - Field methodologies

The location and number of samples to be collected depends on factors such as the sampling strategy, the spatial and temporal variability of hazardous substances in the media to be sampled, the level of confidence desired (either in locating a *HOT SPOT* or in drawing conclusions about a mean concentration), and the costs involved.

As described in the following chapters, a combination of sampling strategies is often recommended to best address the sampling objective(s). When characterizing a *FACILITY* (Sections 1.2 and 2.2), biased sampling should be used whenever information is available with which to reliably select sampling locations. However, there are limitations to using biased sampling strategies alone since unexpected areas of contamination will not be identified. To eliminate sampler bias, statistical or *RANDOMIZED* sampling strategies should often be used to supplement biased sampling. The number of samples can be estimated to locate a *HOT SPOT* of an assumed size and shape with a specified level of confidence (Section 2.2.1.1), to proportionally represent an area of a given size (Section 2.2.1.2) or by selecting a particular data objective to satisfy, such as estimating mean concentration with specified levels of precision and confidence.

For verifying remediation of soils, biased sampling is recommended in small areas (i.e., less than ¼ acre) and statistical sampling is recommended in medium- to large-sized areas (Sections 1.3 and 2.3, respectively). Because identification and consideration of *HOT SPOTS* is necessary for statistical comparison of verification data to criteria, biased sampling may also be necessary.

Hazardous substance concentrations in biased samples must generally be compared to criteria on a point-by-point basis (Section 1.4). If all concentrations meet criteria and the *FACILITY* is believed to be adequately characterized, sampling may be complete. If one or more concentrations are present above criteria, a statistical analysis may be considered for comparison to criteria. Further statistical sampling may be necessary with the sampling objective of statistical estimation of a *REPRESENTATIVE CONCENTRATION* for comparison to criteria (Section 2.4). The additional samples would be collected to obtain a sufficient number of *RANDOMLY* located samples to: 1) allow for an appropriate statistical analysis (see the tabbed section titled, “Statistical Methods”) and 2) adequately represent both exposures for a given exposure pathway and hazardous substance concentrations. However, considerations such as applicability of statistics and adequacy of characterization must first be addressed as described in Section 2.4.

Sampling for the purpose of waste characterization is discussed in Sections 1.5 and 2.5 and described in more detail in the tabbed section titled, “Waste Characterization.”

COMPOSITE SAMPLES

Demonstration of compliance with Part 201 cleanup criteria generally requires collection of discrete soil samples. Compositing of samples is not accepted without prior DEQ approval.

SAMPLE ANALYSIS

All test methods and associated target detection levels must be consistent with those specified in rules and procedures under Part 201. These include:

- analytical methodologies
- target detection levels
- quality control procedures

Generally, constituents in soil will be measured on a total, dry weight basis. Considerations for other media (i.e., groundwater, sediments, waste, leachate) must be addressed on a site-specific basis.

CHAPTER 1: BIASED SAMPLING STRATEGIES

1.1 INTRODUCTION TO BIASED SAMPLING

"Biased" sampling strategies generally involve use of professional judgment to collect soil samples from areas most likely to contain contamination. Often, biased sampling is utilized for smaller areas (e.g., less than a 1/4 acre). However, biased sampling also plays a role on large properties. Biased sampling should be used to focus on known or suspected areas of concern.

Use of biased sampling is premised on enough detailed property information on which to base selection of sample locations. The sample locations are purposefully chosen based on the goal of investigating known or suspected areas of concern. With sufficient knowledge of existing conditions, historic activities, or field indicators (e.g., visual, olfactory, or field screening instrumentation), these areas can be focused on reliably.

Any biased sampling plan requires use of professional judgment. A thorough justification must be documented for each sample location explaining the rationale used to select the location. Without this important detail, biased sampling alone will not be adequate. The reporting section of this document should be carefully followed to ensure adequate documentation of the selection of sample locations (see Section 1.4.2).

It is often necessary to use a combination of sampling strategies for both known or suspected areas of concern as well as areas believed to be unimpacted. Since unexpected areas of contamination will not be identified through biased sampling alone, statistical sampling should often be used to supplement biased sampling. This concept is addressed in the following sections for each of the sampling objectives.

Analytical results from biased sampling must generally be compared to Part 201 criteria on a point-by-point basis and individual exceedances noted. When point-by-point comparisons are made, professional judgment is required to interpret the significance of exceedances that are very close to criteria, or that may be associated with insignificant quantities of a hazardous substance.

A statistical analysis of data generated from biased sampling is generally not appropriate. This is due to the underlying assumptions of most statistical methods used to compare *FACILITY* data to cleanup criteria. One underlying assumption is that the data being evaluated were obtained through *RANDOM* sampling of a single, homogeneous population that can be described by a single statistical distribution (e.g., a normal distribution with a mean of 3.6 and a standard deviation of 0.78). Biased sampling can be used to help identify if this is the case or if differing populations (e.g., *RELEASE* areas) are present.

If statistical sampling is completed in addition to biased sampling, it may be appropriate to combine analytical results from the statistical sampling with some or even all of the biased sampling results in a statistical analysis. However, there are several key considerations which must first be addressed, as described in Section 2.4.1 of Sampling Strategies.

Biased sampling strategies require collection of discrete soil samples. Compositing of samples is not accepted without prior DEQ approval.

The remainder of this chapter provides considerations for selection of biased sample locations according to the following sampling objectives:

- *FACILITY* characterization
- Verification of remediation
- Comparison to criteria for demonstration of compliance
- Waste characterization

Chapter 2 of Sampling Strategies provides statistical sampling methods for each of these objectives.

1.2 *FACILITY* CHARACTERIZATION

FACILITY characterization often includes the collection of samples for the purpose of representing *FACILITY-SPECIFIC BACKGROUND* conditions in addition to the investigation of *RELEASE* areas. Sampling for the identification of *RELEASE* areas is described in Section 1.2.1. Sampling to characterize *FACILITY-SPECIFIC BACKGROUND* conditions is described in Section 1.2.2.

1.2.1 *RELEASE* Area(s)

Sampling strategies for investigation of *RELEASE* areas should incorporate information on known or suspected areas of contamination whenever this information is available. Existing information on areas of contamination is often incorporated in sampling plans through biased sampling of areas most likely to be impacted. Application of a statistical sampling approach such as simple *RANDOM* sampling alone would not be appropriate since it would not incorporate this site-specific knowledge. Known or suspected areas of contamination may not be sampled.

It is often necessary to use a combination of sampling strategies when characterizing soils on a property. For example, biased sampling should be used to focus on known or suspected areas of contamination. However, statistical sampling should also be considered to supplement biased sampling. The necessity of statistical sampling will depend on the accuracy and level of detail of site-specific information used to: 1) select biased sample locations and 2) rule out areas not sampled. For example, if known or suspected contamination is limited to a well defined area, statistical sampling of that area or surrounding areas may not be necessary. If well-defined locations do not exist, statistical sampling may be necessary to either locate the contamination or to adequately demonstrate that the area meets criteria. Statistical sampling should be considered for areas believed to be unimpacted in order to confirm this. Statistical sampling approaches such those described in Sections 2.1.1.1 and 2.2.1.2 can be used.

Use of biased sampling may result in reduced sampling costs when there is sufficient knowledge of known or suspected *RELEASE* areas and adequate documentation of the selected sample locations. However, analytical results from biased sampling must generally be compared to Part 201 criteria on a point-by-point basis. Statistical analysis of biased sampling data is generally not appropriate. If statistical sampling is completed to supplement biased sampling, it may be appropriate to combine analytical results from the statistical sampling with some or even all of the biased sampling results in a statistical analysis for comparison to Part 201 criteria (Section 2.4.2). However, the considerations described in Section 2.4.1 must first be addressed.

The number of samples to be collected will be based on professional judgment, considering the level of certainty and quality of information used to identify the location(s) and extent of known or suspected areas of contamination or to judge an area as unimpacted. The size of appropriate exposure units will also impact the number of samples necessary to adequately characterize a property.

Once sampling has been conducted for the purpose of characterization, a judgment must be made as to whether a site has been adequately characterized. This judgment is generally subjective based upon available information and knowledge of site conditions as described above. Furthermore, a *FACILITY* that was thought to be adequately characterized may need supplemental characterization based on data generated through subsequent *RANDOM* sampling if a statistical analysis is to be used to estimate a *REPRESENTATIVE CONCENTRATION* for comparison to criteria, as described in Section 2.4.2. This may be due to the discovery of unexpected results such as previously unidentified *HOT SPOTS*.

Considerations for Biased Sampling

The biased sampling approach specified in this document recommends sampling from areas most likely to exceed cleanup criteria. The location of soil samples relies on site-specific information on the *RELEASE* or contaminant distribution and specific conditions (e.g., soil type, *RELEASE* type) encountered. Sources of information about a property may include historic and/or current:

- aerial photos,
- property photos,
- detailed property maps,
- utility/activity maps or diagrams,
- historic documentation of activities associated with potential *RELEASES*,
- documentation of containment structures,
- documented field observations (such as stained or visible *RELEASE* areas, odors in an area), and/or
- previous remediation activities.

In addition to the sources of information listed above, other factors may be useful in biasing sample locations and depths towards areas most likely to be contaminated as well as in selection of appropriate analytical parameters. The following describes some of these factors.

a. Sample Locations

Using a biased sampling approach, samples must be collected where they will most likely encounter contamination which could exceed the cleanup criteria. This will minimize the number of samples needed to characterize a property. A sampling strategy that uses bias to choose sample locations is recommended. While it is inappropriate for this document to dictate exact locations for sample collection in this strategy, site specific information concerning the *RELEASE* (e.g., the location of leaks in an underground storage tank or its piping) and soil conditions should be used along with professional judgment and the general information provided here to select appropriate soil sampling locations.

Where to sample:

- Existing information on a property should be used to the degree possible when selecting biased sample locations. Field personnel present during the investigation and/or remediation activities should be sufficiently familiar with the conditions on-site to implement an appropriate biased sampling strategy. A soil sampling strategy should incorporate all pertinent biases of a site which may include, but are not limited to, those listed below:

    - source areas,
    - stained soils,
    - preferential pathways for contaminant migration,
    - other site specific "clues" (e.g., fractures in clays),
    - changes in soil characteristics (e.g., sand/clay interfaces),
    - soil types and characteristics , and/or
    - time lapse between *RELEASE* and investigation.

- For example, if a leak was confirmed on the south side of a tank, more extensive sampling should be conducted on the south side. It would be incorrect to sample the north side of the tank area as extensively as the south side when the leak was known and confirmed to be on the south side of the tank.

b. Depths and Soil Types

Medium sand or larger grains

Medium to larger grain size sand has from 20 to 40% porosity. Most sands in Michigan are composed of quartz, limestone, and small amounts of metamorphic rock fragments. These soils have a low capacity for adsorbing metals or hydrophilic (soluble) organic chemicals. Hydrophobic (insoluble) organic chemicals with low molecular weight will adsorb to this soil in small amounts. Hydrophobic chemicals with high molecular weight will adsorb in moderate amounts (Cline & Brown, 1989). These soils have a low capacity to hold contaminants in the grain interstices due to low capillary action. Contaminants that are held in these soils adhere to the grains themselves in dry soils and are forced into the smaller pore spaces in wet soils (Schwille, 1988).

Where to sample:

- In these soils, the capillary force is low enough to ignore its effects in transporting contaminants lateral to gravity. This is especially true for low surface tension products such as gasoline. Therefore, samples should generally be located below the source and/or *RELEASE* area at depths most likely to intercept contaminant migration.

- Limestone sand grains can act as a buffer to contaminants that cause pH changes (e.g., steel mill pickling acids). For these types of contaminants, the sampler should be on the lookout for intra-granular precipitates. These can appear as grain surface staining or make the soil appear clumpy or aggregated. Soils containing precipitates should be sampled.

Fine sand and silt

These soils have strong capillary action due to the small inter-granular distances. A determination of the fluid surface tension of the spilled product is helpful. High surface tension aids in the ability of a substance to overcome gravity by capillary action. As before, higher molecular weight products can be expected to adsorb to the grains to a greater degree. This allows a product to move lateral to gravity and, to a degree, upward from the leak location. Low surface tension products, such as TCE (trichloroethene), are more likely to go straight down than oils in these kinds of soils. However, the hydraulic head (i.e., the amount of product in the original spill) must be substantial to force a dense non-aqueous phase liquid through a medium with a hydraulic conductivity less than 1×10^{-3} cm/sec (Schwille, 1988).

Where to sample:

- Interfaces between fine sand layers with larger grains above should be sampled. When high surface tension contaminants are suspected, silt layers should be sampled.

Clays

Clay soils are very different from the sands and silts. Clays possess a net negative charge. This causes heavy metal cations (e.g., Cr^{+6}, Cd^{+2}, Pb^{+2}) to adsorb to the clay surface. In fact, this is true for any positive ionizable substance. Clays also have a much greater secondary porosity than primary (primary porosity is the space between the soil particles; secondary porosity is the space between fractures, bedding planes, and soil structures). As a result, spills in clay soils tend to follow preferred pathways. Clays will often show signs of shrinkage cracks or fractures that will allow contaminants to migrate in what would otherwise be considered a "tight" soil in a lab analysis of permeability. Signs of fracturing include "patterned" mottling. This is where the iron (and also manganese) will be oxidized to a red, yellow, or reddish brown color along the crack while the matrix remains the reduced blue/gray color (Lindsay, 1979). Additionally, studies have also indicated that dense non-aqueous phase liquids (DNAPL) tend to reside in clay layers where those conditions exist.

Where to sample:

- It is very important to take clay soil samples from fractures. The fractures are the avenue of travel for contaminants in clay soils. Clay soils may also have sand lenses which should always be sampled. Sand lenses in clays tend to collect fluids. As such, they may harbor contaminants.

Organic carbon content of soil

The organic carbon content of soils is a key factor in the ability of any soil to adsorb contaminants. For a variety of reasons (Lindsay, 1979), an increase in organic carbon content leads to an increase in the adsorption of several classes of chemicals.

Where to sample:

- Soils that appear to have excess organic carbon (e.g. peat, muck, darker soils) should be preferentially sampled.

Bedrock

RELEASES into bedrock present difficult problems. Unlike clay, some bedrock formations have substantial primary porosity as well as secondary porosity. In Michigan, these are sandstones, conglomerates, and brecciated/coarse grained limestone. Examples of bedrock in Michigan with low primary porosity are fine grained limestone, shale, and crystalline metamorphic rocks (e.g., gneiss). If the sampler is unaware of the type of bedrock that is being investigated in a *RELEASE* area, a geologist must be consulted.

Where to sample:

RELEASES into areas with shallow bedrock that have significant primary porosity must be sampled in both the fractures and the matrix. Bedrock without primary porosity should have sampling predominantly in the fractures as in the clay situation. Weathered zones in bedrock will hold contaminants better than unweathered zones. This is due to the increased number of adsorption sites available in weathered rock.

c. Changes Over Time and Chemical Transformations

Many organic chemicals may undergo aerobic and anaerobic degradation. A detailed description of these processes is beyond the scope of this document. The subject is approached here, however, to be sure that samplers are aware that the chemical(s) spilled may not be the only chemical(s) in the soil after a transformation has occurred. These transformations should be considered in the *FACILITY* investigation.

The professional literature contains many articles on this subject (Cline and Brown, 1989; Borden and Bedient, 1987; Wilson and Wilson, 1985). The interested reader is directed to these articles.

What to analyze:

- Analyses should be done for all chemicals that have been *RELEASED* as well as those identified as breakdown products of these chemicals.

- For example, soils surrounding a tank containing tetrachloroethylene that had valve leakage occurring over the last ten years should be sampled for the tetrachloroethylene as well as all breakdown products (TCE, dichloroethylene and vinyl chloride).

d. Exposure Pathways

The characteristics of the exposure pathway for each applicable cleanup criterion are critical to consider when locating samples, since sampling data is ultimately compared or interpreted relative to a cleanup criterion. Information on land use, receptor (exposed) population, exposure medium, exposure route (e.g., oral, inhalation and or dermal), hazardous substance and for some criteria pathways contaminant transport/migration, is all integrated into the development of each cleanup criterion. It follows, therefore, that these same characteristics should be considered when samples are collected for comparison to criteria.

Each cleanup criterion conveys an acceptable exposure concentration for a particular exposure pathway. An objective of biased sampling, therefore, may be to purposely collect samples from locations that will represent the unique characteristics of the exposure pathway of concern. The characteristics of each exposure pathway must be considered to assure that sample results are obtained from representative/appropriate locations. For some pathways, exposure to a

hazardous substance occurs in the medium being sampled (e.g., drinking water and soil direct contact criteria), while for other pathways exposure is to a different medium or location from that which is sampled (e.g., soil to groundwater protection criteria, GSI criteria). Biased sampling strategies may, therefore, be designed to achieve one of the following objectives depending on the criteria/pathway of interest: 1) represent the concentration in the medium to which a person may be exposed, or 2) represent the concentration in a medium that is protective of a different exposure medium.

The phrase "may be exposed" is underlined to emphasize that exposures under the generic context of unrestricted future use of property could occur to areas within the soil or groundwater contaminant profile that are currently not available for exposure, but may be in the future depending on property activities.

The exposure pathways considered under Part 201 are listed in the tabbed section titled, "Applicability of Statistics."

1.2.2 *BACKGROUND*

Under Part 201, the term *BACKGROUND* is defined as:

> *the concentration or level of a hazardous substance which exists in the environment at or regionally proximate to a site that is not attributable to any release at or regionally proximate to the site.*

Consequently, *BACKGROUND* samples must be collected from areas that are representative of *BACKGROUND* conditions and have not been impacted by a *RELEASE* at or regionally proximate to the site.

According to Section 20a(11), when *BACKGROUND* concentrations of a hazardous substance are greater than the corresponding Part 201 risk-based criterion, *BACKGROUND* becomes the Part 201 criterion. Consequently, *FACILITY* data will generally be compared to *BACKGROUND* concentrations only when *BACKGROUND* concentrations are greater than the applicable risk-based criterion.

Establishing *BACKGROUND* concentrations for soil can be accomplished by utilizing Operational Memorandum #15. The types of *BACKGROUND* that will generally be considered include: 1) *STATEWIDE DEFAULT BACKGROUND*, 2) *REGIONAL BACKGROUND*, and 3) *FACILITY-SPECIFIC BACKGROUND*. Additional information on each type of *BACKGROUND* is provided in Chapter 4 of the tabbed section titled, "Statistical Methods."

Sampling considerations for *FACILITY-SPECIFIC BACKGROUND* are described below. *FACILITY-SPECIFIC BACKGROUND* samples are not typically collected using statistical or probabilistic approaches. An effort is made to reflect the same natural conditions observed at a *FACILITY.* Consequently, *FACILITY-SPECIFIC BACKGROUND* data are somewhat biased. Although not described here, statistical or probabilistic methods could be incorporated into *FACILITY-SPECIFIC BACKGROUND* soil sampling. If multiple soil types or horizons are present, this could be accomplished through *RANDOM* sampling of each soil type or horizon independently.

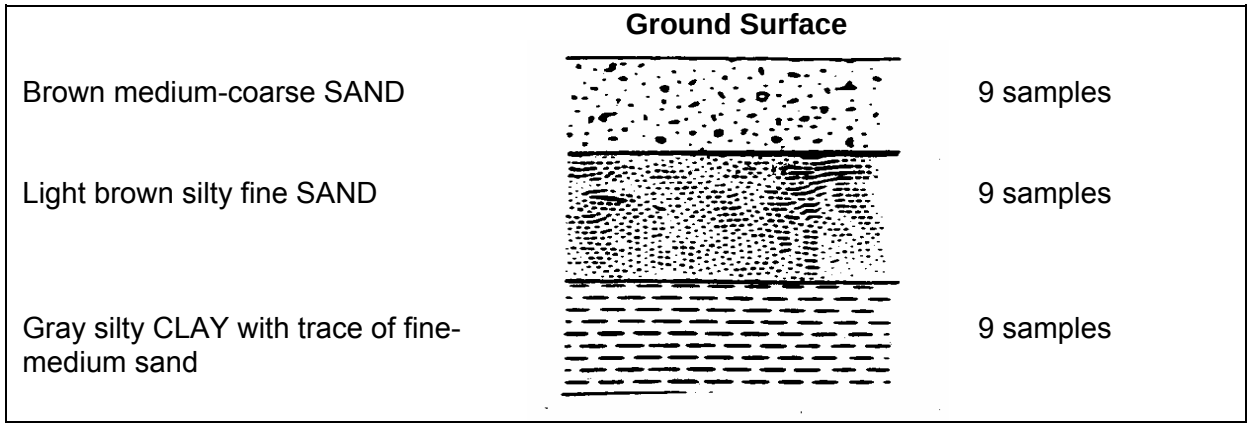
Number of *FACILITY-SPECIFIC BACKGROUND* Samples

Approximately nine samples must be used to establish *FACILITY-SPECIFIC BACKGROUND* concentrations in soils. This recommendation is based on statistical considerations only. It is necessary that an adequate number of samples is available to evaluate the underlying statistical distribution of the *FACILITY-SPECIFIC BACKGROUND* data (i.e., normal, lognormal, or neither).

The goal of collecting *FACILITY-SPECIFIC BACKGROUND* data is to adequately represent the magnitude and variability of naturally occurring concentrations in samples collected from the *FACILITY* of interest. Ideally, a *FACILITY-SPECIFIC BACKGROUND* data set should provide an equal representation of natural soil conditions identified at the *FACILITY*, the key difference being the potential for a *RELEASE*. If a *FACILITY* and the numbers of samples being collected from that *FACILITY* are large, it would be prudent to collect a sufficient number of *FACILITY-SPECIFIC BACKGROUND* samples to adequately represent the same naturally occurring conditions observed in *FACILITY* samples. For this reason, nine samples may not always be adequate to represent or characterize the magnitude and variability of *FACILITY-SPECIFIC BACKGROUND* concentrations.

Furthermore, if multiple soil horizons are present, approximately nine *FACILITY-SPECIFIC BACKGROUND* samples should be collected *from each soil horizon* and a *FACILITY-SPECIFIC BACKGROUND* concentration established for each horizon separately. It is generally not appropriate to combine data from multiple populations or statistical distributions for statistical analysis since this will inflate the variability of the data set, resulting in inflated *BACKGROUND* concentrations.

Example 1.1 Collection of *BACKGROUND* When Multiple Soil Horizons are Present



Additional Considerations for Selection of *FACILITY-SPECIFIC BACKGROUND* Sample Locations

Many factors can play a part in the *BACKGROUND* concentrations of a chemical in soil. Consideration of these factors is particularly important when establishing *FACILITY-SPECIFIC BACKGROUND* concentrations. For example, the geologic origin (e.g., the parent rock) of glacial drift may have been high in copper, lead, or other metals that may be potential contaminants. Additionally, the hydrogeologic situation can alter the quantity of these elements. Groundwater recharge areas (e.g., highlands) are frequently leached of metals while groundwater discharge areas (e.g., swamps, floodplain) are the recipients of leached metals. Thus, sites in low areas will usually have higher *BACKGROUND* concentrations than upland areas. Other conditions, such

as precipitation and atmospheric fallout from widely dispersed human and natural activities, also affect soil concentrations.

In addition, an estimate of contamination depth should be made and *BACKGROUND* samples taken at comparable depths for the particular soil type. This estimate should be made based on waste type, contaminant mobility, operation practices, and soil type (sand, silty sand, clay).

Selection of Analytical Parameters

BACKGROUND should be established as appropriate for site-specific waste constituents, specific chemicals used in various processes, *FACILITY* operations, or remedial investigation results. Sample analyses will generally include metals and other site-specific inorganic constituents of concern. Analytical parameters could possibly include organic constituents if consideration of *NON-RELEASE ANTHROPOGENIC BACKGROUND* conditions is justified.

1.3 VERIFICATION OF REMEDIATION

When verifying remediation of small areas (i.e., less than 10,890 ft^2 or 1/4 acre), biased sampling is recommended. "Biased" sampling involves collecting soil samples from areas most likely to still exceed cleanup criteria after remediation. When biased sampling is conducted to verify remediation of soils, analytical results must generally be compared to Part 201 cleanup criteria on a point-by-point basis. A statistical analysis of verification sample results may not be used to compare the data to Part 201 cleanup criteria.

Although it is unlikely, it is possible that biased sampling could be used to verify remediation in areas larger than 10,890 ft^2. However, statistical sampling methods are generally recommended for these larger areas. (See Section 2.3 of Sampling Strategies.) As noted in Section 2.3, when statistical sampling methods are used, it may be appropriate to conduct a statistical analysis of verification sample results for comparison to Part 201 criteria; however, the considerations summarized in Section 2.4 must first be addressed.

Compositing samples for verifying soil remediation is not acceptable without prior DEQ approval. When verifying a soil remediation is complete, contaminant concentrations will be low. Compositing may result in the contaminant concentrations not being representative of what remains in the soil. If concentrations are low, compositing may dilute the concentrations of a contaminant to below its threshold detection limit. Additionally, if contamination is indicated in a composite sample, the location of the contamination remains unknown.

Any biased sampling plan requires professional judgment. A thorough justification must be documented for each sample location explaining the rationale used to select the location. Without this important detail, it is often necessary to apply a broader sampling strategy to include unknown areas. (See Section 1.4.2)

1.3.1 Selecting Numbers and Locations of Verification Samples in Excavations

Verifying that contaminated soil is remediated by means of excavation requires samples from the excavation bottom and sidewalls. The following tables provide the minimum number of samples necessary to verify cleanup for various size excavations. Considerations for selection of biased sample locations are also discussed.

It should be noted that "excavation" as used here refers only to that area excavated for remediation purposes and being verified to meet Part 201 cleanup criteria.

When biased sampling is used for verifying remediation, a point-by-point comparison of verification sample results to cleanup criteria is specified. If the cleanup criteria are exceeded at any point, this verification methodology may require additional excavation at that point until the criteria are attained.

Number of Samples

The following tables are used to determine the minimum number of samples necessary from the floor and sidewalls of an excavation no greater than 10,890 ft^2 using a biased sampling approach. If the area of the excavation floor exceeds 10,890 ft^2, refer to Section 2.3 of Sampling Strategies.

Determine the minimum number of excavation floor samples from the table below.

Table 1.1 Number of Excavation Floor Samples

Area of Floor (ft^2)	*Number of Samples*
< 500	2
500 < 1,000	3
1,000 < 1,500	4
1,500 < 2,500	5
2,500 < 4,000	6
4,000 < 6,000	7
6,000 < 8,500	8
8,500 <10,890	9

Sidewall samples are required to verify that the horizontal extent of contamination has been remediated. Use Table 1.2 to determine the minimum number of required sidewall samples. In no case is less than one sample on each sidewall (i.e., four) acceptable. In the case of irregularly shaped excavations in which four walls are not readily discernible, divide the total wall area into four segments of approximately equal size. Sidewall samples should be located in accordance with "biases" outlined below.

Table 1.2 Number of Excavation Sidewall Samples

Total Area of Sidewalls (ft^2)	*Number of Samples*
< 500	4
500 < 1,000	5
1,000 < 1,500	6
1,500 < 2,000	7
2,000 < 3,000	8
3,000 < 4,000	9
> 4,000	1 sample per 45 lineal feet of sidewall

Considerations for Biased Sampling

"Biased" sampling involves collecting soil samples from areas most likely to still exceed cleanup criteria. Specific considerations for biasing sample locations are described in detail in Section 1.2.1 under *FACILITY* characterization. The fundamental approaches for biasing sample location are basically the same for verifying remediation; however, the biased sampling is now focused on post-remediation activities.

A site may have an appropriate number of samples collected for verification, but if the samples are not collected from the appropriate locations and adequately reported remediation may not be considered adequate. The location of the sample collection points relies on site-specific analysis of the *RELEASE* or contaminant distribution and the soil types encountered in the excavation. For example, when selecting verification sample locations in an excavation, more extensive verification sampling should be completed on the south side of the excavation if a leak was confirmed on the south side of a tank. It would be incorrect to sample the north side of an excavation pit as extensively as the south side when the leak was confirmed on the south side of the tank.

Sampling and analyzing the locations most likely to have contaminants can minimize the number of samples needed to verify remediation is complete. Professional judgment and site-specific knowledge are required for selection of biased sampling locations. The verification report must accurately locate and describe all sample locations. A thorough justification must be documented for each sample location explaining the rationale used to select the location.

1.3.2 Selecting Numbers and Locations of Soil Verification Samples for Ex Situ Remedies

Verification samples from ex situ remediation activities can also be collected in a biased manner. Again, sampling and analyzing the locations most likely to have contaminant concentrations above Part 201 cleanup criteria can minimize the number of samples needed to verify remediation is complete. However, biased verification soil sample results must generally be compared to cleanup criteria on a point-by-point basis. A statistical analysis of data generated from biased sampling is generally not appropriate.

Number of Samples

The number of verification soil samples to be collected from a soil pile should be based on the volume of the soil pile. The following table provides recommended numbers of verification samples for biased sampling.

Table 1.3 Number of Samples for Ex Situ Remedies

Volume (cubic yards)	0-25	26-100	101-500	501-1,000	1,001-2,000	> 2,000
Number of samples (depending on basis of bias)	3-4	6-8	8-10	10-12	13-15	15 + 3 for every additional 500 cubic yards

If it is demonstrated that concentrations of hazardous substances in the soil under consideration represent a single, homogeneous population, the effectiveness of ex situ soil remedies may be verified by three-dimensional *RANDOM* soil sampling. Refer to Section 2.2 of Sampling Strategies for recommended statistical sampling strategies. Because these strategies are two dimensional, a vertical component must be added. Certain ex situ remedies, such as bio-piles or aboveground vapor extraction, may be more amenable to statistical sampling strategies or batch sampling. Any *PROPOSED* sampling strategy for ex situ remedies should be pre-approved by the DEQ.

Considerations for Biased Sampling

Specific considerations for biasing sample locations are described in detail in Section 1.2.1 under *FACILITY* characterization. The fundamental approaches for biasing sample location are basically the same for verifying remediation; however, the biased sampling is now focused on post-remediation activities.

1.3.3 Selecting Numbers and Locations of Soil Verification Samples for In Situ Remedies

In situ verification soil sampling is required to evaluate the effectiveness of the remedy or to *PROPOSE* closure upon completion of an in situ soil corrective action (e.g., soil vapor extraction, bioventing, in situ bioremediation, and natural attenuation). The purpose of the in situ verification soil sampling is to demonstrate that the entire volume of contaminated soil is below Part 201 cleanup criteria. Because the in situ verification soil sampling is characterizing a volume of soil, additional samples will be required beyond the number of sidewall and floor samples recommended above for excavations, as described below.

Biased verification soil sample results must generally be compared to cleanup criteria on a point-by-point basis. A statistical analysis of data generated from biased sampling is generally not appropriate.

Number of Sample Locations

The number of biased sampling locations should be selected using Tables 1.1 and 1.2 shown in Section 1.3.1 (Excavation Floor Samples and Excavation Sidewall Samples, respectively). Table 1.2 is also considered since it is important to verify remediation around the lateral extent of the remediated area.

Statistical sampling methods are generally recommended for areas larger than 10,890 ft^2. These methods are described in Section 2.2 of Sampling Strategies. Because these strategies are two dimensional, a vertical component must be added. Any *PROPOSED* sampling strategy for in situ remedies should be pre-approved by the DEQ.

Considerations for Biased Sampling

Specific considerations for biasing sample locations are described in detail in Section 1.2.1 under *FACILITY* characterization. The fundamental approaches for biasing sample location are basically the same for verifying remediation; however, the biased sampling is now focused on post-remediation activities.

A biased sampling strategy should also be used to select the vertical sampling intervals that are the most likely to still contain contaminant concentrations above Part 201 cleanup criteria. The following areas should be considered for vertical sampling intervals: areas of probable high contaminant concentrations (based on previous sample results, field observations, and/or the field screening instrumentation) and areas where the flow of air, water and/or nutrients will be impeded (e.g., low permeability lenses and the capillary fringe zone). If air flow modeling indicates the possible presence of stagnation zones, these areas should be sampled.

At least one sample should be collected from each five feet of the verification sample boring, with the exception of borings that are advanced through uncontaminated backfill. Verification soil samples are not required from uncontaminated backfill material. If there is no basis for further biasing the sample from within a five-foot interval, then the five-foot interval may be subdivided into six-inch intervals, and an interval *RANDOMLY* selected for sampling.

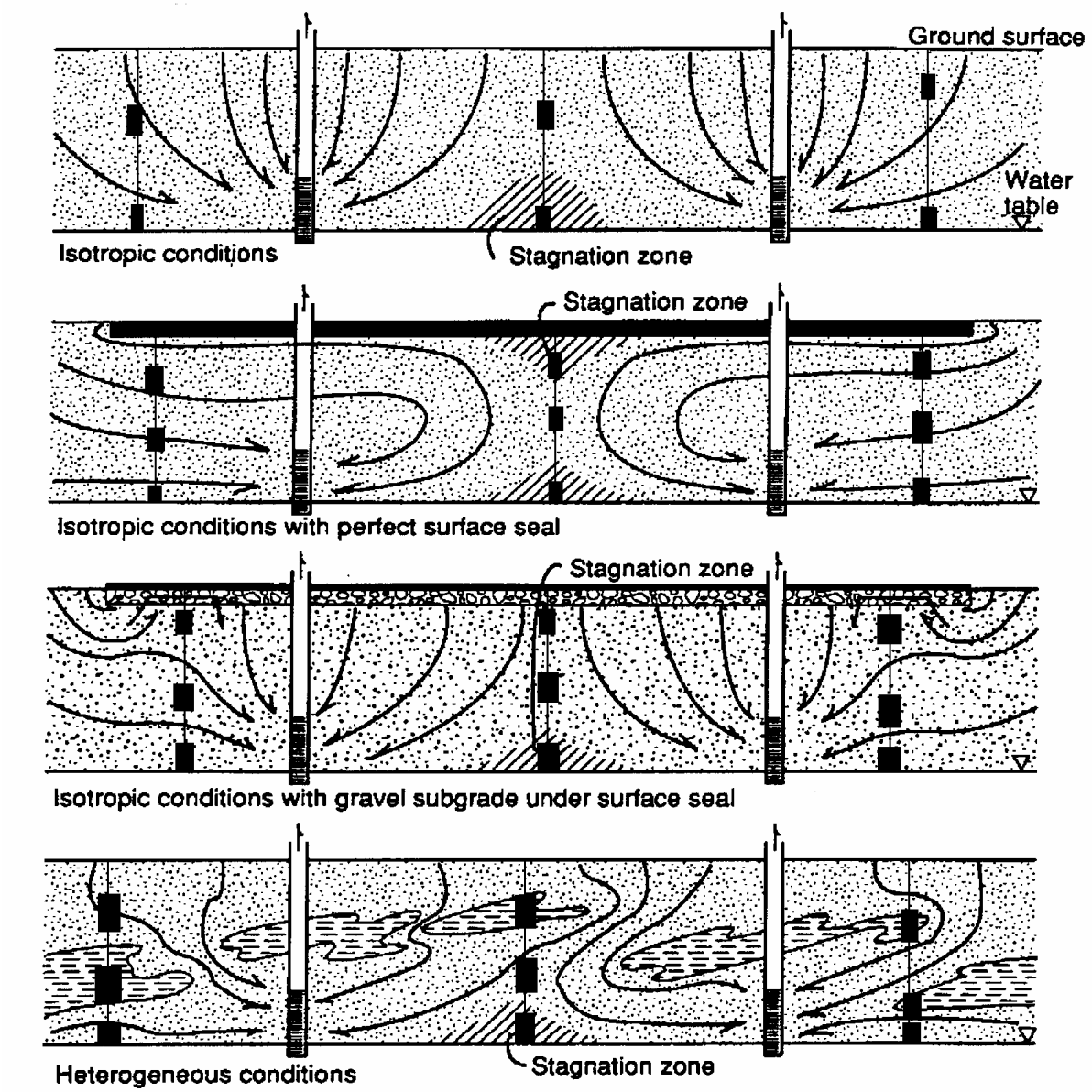
The verification soil borings must extend at least as far as the known depth of the soil contamination. If a confining layer is determined to be the lower boundary of the contamination (as should have already been determined during the investigation phase), at least one soil sample should be collected from the top of the lower confining layer to verify this. If the confining layer is not the lower boundary of the contamination, then a sampling of this layer and below must be conducted in relation to the remediation activity.

Other Considerations

Partial dewatering of an aquifer can allow soil vapor extraction and/or bioventing systems to remediate the residual soil contamination below the water table. If the groundwater potentiometric surface is being lowered during remediation, then the verification soil samples should be collected while the soils in question are still dewatered. The groundwater dewatering system should then be discontinued and verification groundwater samples collected.

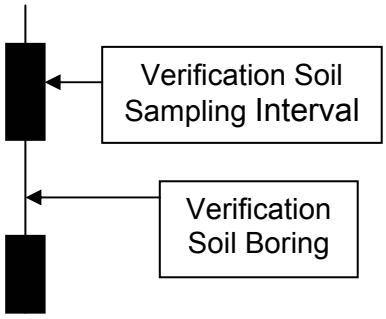
Examples of biased strategies for vertical sampling are shown on the following page.

Example 1.2 Examples of Biased Vertical Sampling Strategies



Note: Not to scale, for conceptual discussion purposes only
Flow is three dimensional. Recharge also occurs in the dimension perpendicular to the drawing.

(Revised from WDNR, 1993)



1.4 COMPARISON TO CRITERIA

1.4.1 Demonstrating Compliance on a Point-by-Point Basis

Use of biased sampling may require fewer samples to demonstrate compliance than statistical or probabilistic approaches. However, a limitation to biased sampling is that unexpected areas of contamination will not be identified. Consequently, statistical sampling should often be used to supplement biased sampling.

Analytical data generated using biased sampling strategies must generally be compared to Part 201 criteria on a point-by-point basis and individual exceedances noted. When point-by-point comparisons are made, professional judgment is required to interpret the significance of exceedances that are very close to criteria, or that may be associated with insignificant quantities of a hazardous substance.

Interpretation of Analytical Results

If all samples in an area are below cleanup criteria based on biased sampling and the area is believed to be adequately characterized, the investigation for this area may be complete. A thorough justification must be documented for each sample location explaining the rationale used to select the location. Adequate documentation of all sample locations must also be provided with respect to known or suspected *RELEASE* areas.

If one or more samples contain contaminant concentrations above cleanup criteria, this may indicate one or more of the following:

- additional site characterization is necessary to better understand the exceedance (e.g., if no exceedances were expected in an area/depth), and possibly a change in sampling strategy from biased to statistical (e.g., identification of an unexpected Hot Spot, unless documented to be a localized Release, may necessitate statistical sampling with the objective of identifying similar Hot Spots (see Section 2.2.1.1);
- vertical and horizontal delineation of elevated concentrations in the area of the biased sample location is necessary;
- alternate approaches should be considered to demonstrate appropriate pathway protection (e.g., leach testing, if a protection of groundwater criterion is exceeded); and/or
- remediation (or further remediation) is necessary.

Statistical analyses of data from biased sampling is generally not appropriate. This is due to the underlying assumptions of most statistical methods used to compare *FACILITY* data to cleanup criteria. One underlying assumption is that the data being evaluated were obtained through *RANDOM* sampling of a single population that can be described by a single statistical distribution (e.g., a normal distribution with a mean of 3.6 and a standard deviation of 0.78).

If statistical sampling is also completed in an area that was previously sampled using a biased approach, it may be appropriate to combine analytical results from the statistical sampling with some or even all of the biased sampling results in a statistical analysis. See Section 2.4.2 of Sampling Strategies for further detail. However, it is first necessary to address the considerations summarized in Section 2.4.1.

1.4.2 Comparison of *FACILITY* Data to *FACILITY-SPECIFIC BACKGROUND* Concentrations

When Part 201 criteria are established as *BACKGROUND* concentrations, the objective becomes to determine whether the *FACILITY* concentrations are significantly higher than *BACKGROUND* concentrations for a hazardous substance. To make this determination in most cases, *FACILITY* data will be compared to *FACILITY-SPECIFIC BACKGROUND* concentrations on a point-by-point basis. That is, concentrations of each hazardous substance in each *FACILITY* sample will be compared to directly to the *FACILITY-SPECIFIC BACKGROUND* concentration and individual exceedances will be noted. This will most often be the case when *FACILITY* samples are collected in a biased manner. However, it may also be necessary to compare *FACILITY* data collected using statistical sampling strategies to *FACILITY-SPECIFIC BACKGROUND* concentrations on a point-by-point basis.

For information on establishment of *BACKGROUND* concentrations, see Chapter 4 of the tabbed section titled, “Statistical Methods.”

1.4.3 Recommended Summary Report Format for Biased Sampling

Summary Reports for sites utilizing biased sampling strategies must identify the number and location of samples and provide the justification of the sample locations selected. The Summary Report should contain site maps and cross-sections, drawn to scale, which depict the area and volume of contaminated soil; any remediation area(s); the locations of any air/fluid injection and/or extraction wells with their estimated zones of influence; the sampling grids; and the soil boring/sample locations and vertical sampling intervals. The Summary Report should also include the calculations for determining the sampling grid intervals and a statement documenting the sampling strategy utilized for selection of the sampling locations.

The list below identifies items recommended to properly evaluate a closure certification. These items are not "absolutes." Other information or substitutions may be provided which technically justify and certify a "clean closure."

The report must include the following:

1. MAP(s) and CROSS SECTIONS
   Provide a scaled map of the investigated and remediated area (i.e. the estimated *RELEASE* area, or floor and walls of an excavation, or the vertical and horizontal area treated for in situ remediations, etc.) with sample locations identified. If a cross section is utilized to display the remediation activities and data, it should show the relation of key elevations, depict the stratigraphy, fractures, soil types, discolorations, unusual characteristics, possibly indicate the original *RELEASE* source location, sample locations/elevations, etc.

2. SAMPLE LOCATION RATIONALE
   - All sample locations including *BACKGROUND* samples, investigative samples, and/or verification samples
   - Sample depths
   - Sample collection procedures
   - Describe basis of sampling biases and the rationale used for collecting each sample (e.g., clay fractures, discolored soil, location of leak in tank)

3. DATA ANALYSES
   - Analytical parameters
   - Analytical methods used
   - Method detection limits
   - Laboratory Quality Assurance/Quality Control
   - Summary of decontamination procedures

4. STATISTICAL ANALYSIS OF BACKGROUND DATA, IF APPLICABLE
   - Lab results/data tabulation
   - Complete statistical calculations as described in Chapters 1, 2, and 4 of the tabbed section titled, "Statistical Methods"
   - Narrative explanation of *BACKGROUND* concentrations
   - Point-by-point comparisons of *FACILITY* data to cleanup criteria and/or *BACKGROUND* concentrations

5. CONCLUSIONS
   This portion of the report should include a summary of activities and final conclusions, accounting for the work and testing completed and how completed activity(ies) fit in with the site-wide remediation plan (i.e. land use issues, possible closure requirements, whether there is a Remedial Action Plan, resumption of operations, etc.)

1.5 WASTE CHARACTERIZATION

Characterization of wastes for the purpose of disposal must often be addressed at Part 201 *FACILITIES*. The regulatory context for waste characterization is different than the context described in previous sections of this chapter, however. Sections 1.1 through 1.4 describe sampling and analysis of data for the purpose of demonstrating compliance under Part 201. Waste characterization is regulated under Parts 111 and 115. Consequently, sampling strategies and statistical analysis of data for this purpose have been described in a separate tabbed section titled, "Waste Characterization."

CHAPTER 2: STATISTICAL SAMPLING STRATEGIES

2.1 INTRODUCTION TO STATISTICAL SAMPLING

Statistical sampling, also referred to as unbiased or probabilistic sampling, is based on the theory of *RANDOM* chance probabilities in order to choose samples which are representative of a given area. The probability of selecting any sampling location is equal or at least known as with stratified sampling designs. Because sampler bias is not of concern, the error in data accuracy of a *RANDOM* sampling scheme can be objectively measured. Furthermore, knowledge of the contaminant distribution is not always necessary depending on the sampling objective.

In some cases it is preferable to choose statistical sampling strategies over biased sampling strategies since they can be used to produce increased data accuracy while eliminating sampler bias. This will depend on the purpose of sampling and the amount of available information with which to bias sampling. In some cases, a combination of approaches will yield the most comprehensive information.

Several statistical sampling strategies can be used to produce an unbiased, representative sampling program. The principles behind the three basic types of *RANDOM* sampling and the situations for which they are best suited are described below. To achieve true *RANDOM* sampling, composite sampling is not acceptable.

1. ***Simple RANDOM sampling*** is a method that requires little or no prior knowledge of material distribution. It relies on *RANDOM* chance probability theory – where each sampling location has an equal and known probability of being selected. In this way, sampling error can be accurately estimated. Often, the area of interest is sectioned into a two- or three-dimensional grid pattern and *RANDOM* coordinates are chosen for sampling.

2. ***Systematic RANDOM sampling*** is an extension of simple *RANDOM* sampling that may produce a more efficient sampling survey. It can be more efficient by reducing the sampling error while maintaining the sample number, or by reducing the number of samples needed to achieve a specified sampling error, or by reducing the cost of collection. This method also requires little or no knowledge about the waste distribution, but bias and imprecision can be introduced if unseen trends or cycles exist. Two methods used to select sample locations under this method follow.

    A) *RANDOMLY* select a transect or transects and sample at pre-selected intervals.

    B) Pre-select both the transect or transects and the sampling interval and starting from a *RANDOMLY* selected point. This is the method used most throughout this chapter.

3. ***Stratified RANDOM sampling*** requires some knowledge about the waste distribution. When stratification is known or suspected, sampling efficiency can be improved by dividing the material into strata that are more homogeneous than the total area. Simple or systematic *RANDOM* sampling techniques can then be used to sample each stratum independently. Each stratum is divided into a grid pattern and the sampling points are selected *RANDOMLY*. If the area is vertically stratified, the sampling points in each stratum are selected *RANDOMLY* and then selected depths are sampled. If the area is horizontally stratified, the sampling

points within each stratum are selected *RANDOMLY*, but the total depth is sampled. An analysis of variance (ANOVA) may be used to determine if the analytical results differ significantly among strata. This can help evaluate whether use of stratified *RANDOM* sampling was necessary and statistically valid. When the volumes of the strata differ or the number of samples within each stratum differs, the results must be weighed appropriately to avoid bias if the data are to be combined in order to draw conclusions.

Of these methods, Systematic *RANDOM* sampling is generally recommended for each sampling purpose described in this chapter. As noted above, this approach is often the most efficient since it involves collection of samples at equal intervals, simplifying the location of samples in the field. Furthermore, systematic *RANDOM* sampling can serve many purposes. When samples are collected on a regular grid interval, conclusions can be drawn about the size of a *HOT SPOT* likely to be identified (or missed), as described in Section 2.1. Furthermore, because the sampling locations are *RANDOMIZED* through systematic *RANDOM* sampling (i.e., by *RANDOMLY* selecting transects and/or the initial sampling point), it may be appropriate to include the analytical results in a statistical analysis for the purpose of comparison to Part 201 cleanup criteria. However, the considerations described in Section 2.4.1 must first be addressed.

Three methods for establishing grids intervals for systematic *RANDOM* sampling are described. Selection of the appropriate method will depend on the purpose for sampling.

1) **Establish a grid interval based on the size of a *HOT SPOT* to be identified.** *HOT SPOT* shape and size and the level of confidence for finding the *HOT SPOT* are prespecified in this approach. This method is described in Section 2.2 for the purpose of *FACILITY* characterization. See Section 2.2.1.1 for details.
2) **Establish a grid interval based on the size of the area to be sampled.** This approach was originally presented in the medium- to large-site portion of the April 1994 MDEQ guidance document titled, "Verification of Soil Remediation (Revision 1)". This method is described in both Sections 2.2 and 2.3 since it may be useful for either *FACILITY* characterization or verification of remediation. See Section 2.2.1.2 and 2.3.1 for details.
3) **Collect *RANDOM* samples for the purpose of demonstrating compliance with Part 201 criteria using statistics.** This method involves collection of a prespecified number of samples (minimum of nine) for the purpose of estimating a *REPRESENTATIVE CONCENTRATION* for comparison to criteria. As described in Section 2.4, use of this method presumes that the area has already been adequately characterized and represents a single homogeneous population that can be described by a single statistical distribution.

It is often necessary to use a combination of sampling strategies. For example, biased sampling is commonly completed before statistical sampling strategies are employed. Statistical sampling strategies should be considered to supplement characterization. Once characterization is complete, it may be necessary to collect additional samples for the purpose of using statistics to estimate a *REPRESENTATIVE CONCENTRATION* for comparison to criteria.

When conducting the statistical analysis, it may be appropriate to combine some or all of the data from biased sampling with data collected using statistical sampling strategies. See Section 2.4 for further detail. See also the tabbed section titled, "Statistical Guidesheets" for key considerations which must be addressed before a statistical analysis is conducted to compare data to Part 201 criteria.

Statistical sampling strategies require collection of discrete soil samples. Compositing of samples is not accepted without prior DEQ approval.

The remainder of this chapter describes statistical sampling strategies for each of the following sampling objectives:

- *FACILITY* characterization
- Verification of remediation
- Comparison to criteria for demonstration of compliance using statistics
- Waste characterization

Chapter 1 of Sampling Strategies provides considerations for selecting biased sample locations for each of these objectives.

2.2 *FACILITY* CHARACTERIZATION

Statistical sampling strategies may be useful as part of an overall sampling plan for *FACILITY* characterization. This section provides several statistical sampling strategies for this purpose.

In addition to the investigation of *RELEASE* areas, *FACILITY* characterization often includes the collection of samples for the purpose of representing *FACILITY-SPECIFIC BACKGROUND* conditions. Sampling for the identification of *RELEASE* areas is described in Section 2.2.1. Sampling to characterize *FACILITY-SPECIFIC BACKGROUND* conditions is described in Section 2.2.2.

2.2.1 *RELEASE* Area(s)

An important goal of *FACILITY* characterization is to identify existing environmental conditions in areas potentially affected by *RELEASE*s of hazardous substances. This includes identifying the nature and extent of contamination and whether *HOT SPOTS* are present in these areas. The answers to these questions will play a role in subsequent site evaluations and/or actions.

HOT SPOTS

For the purpose of evaluating data from Part 201 *FACILITIES*, a *HOT SPOT* is defined as:

> *Two or more adjacent sample locations in reasonably close proximity at which concentrations are sufficiently above criteria and surrounding location (i.e., spatially correlated concentrations sufficiently above criteria) to indicate that they:*
>
> - *represent a different statistical population and*
> - *pose a potential risk that should not be masked by a statistical analysis.*

Professional judgment may be used to determine if the magnitude of concentrations and/or the number and proximity of spatially correlated samples above criteria are sufficient to classify an area as a *HOT SPOT*. That is, the data should support the conclusion that the samples reflect a second statistical population influenced by a localized *RELEASE*, such as a tank spill, resulting in concentrations above criteria. Spatially correlated concentrations below criteria may also exist; however, these will not be classified as *HOT SPOTS* for the purpose of statistical analysis. Particular consideration should be given to contaminants that are present above soil saturation

(Csat) screening levels and contaminants for which criteria are based on acute toxicological effects and/or physical hazards.

A single sample location may represent a potential *HOT SPOT*, or an area at which concentrations are sufficiently above criteria to necessitate additional sampling to determine if a *HOT SPOT* exists. Once again, professional judgment may be used by staff to determine if the magnitude of the concentration is sufficient to warrant additional sampling.

To identify *HOT SPOTS*, data should be qualitatively evaluated for spatial correlation, or patterns indicating that high or low concentrations generally occur in localized areas. Spatial correlation may exist horizontally and/or vertically. Spatial correlation may also be seen along geological bedding planes or between different lithologies. For example, contaminants could accumulate on top of a sloping clay layer, resulting in spatial correlation even though depth to contamination will vary.

HOT SPOT areas identified for one exposure pathway/condition may not represent *HOT SPOTS* for another exposure pathway/condition due to differences in criteria, *EXPOSURE UNITS* sizes, and significance of exceedances.

If *HOT SPOTS* are present, they must be addressed independent of other non-*HOT SPOT* areas, possibly through remediation or mitigation of exposures through institutional controls. A statistical analysis combining *HOT SPOT* data with non-*HOT SPOT* data is not appropriate.

Considerations for Statistical Sampling

As described in Chapter 1, sampling strategies for *FACILITY* characterization should incorporate information on known or suspected areas of contamination whenever this information is available. Often, biased sampling is conducted for this purpose. However, use of biased sampling to demonstrate compliance with Part 201 criteria requires sufficient knowledge of existing conditions, historic activities, or field indicators (e.g., visual, olfactory, or field screening instrumentation) and thorough documentation of the selection of sampling locations based on this information. Consequently, there is a limitation that must be recognized when using biased sampling for the purpose of *FACILITY* characterization: the resulting information is only as complete and accurate as the information used to select sample locations.

For example, a previously undocumented area of contamination may be present; however, this area may be missed using a biased sampling approach, particularly if there are no observable field indications that the contamination exists. Furthermore, if biased sampling is conducted in an area of known or suspected contamination, areas of contamination can still be missed if the information used to select sample locations is not accurate or sufficiently detailed. In these instances, statistical sampling should be used to supplement biased sampling.

Example 2.1 Example of When Statistical Sampling Strategies Should Be Considered

It is known that waste materials were placed in an area. However, there is limited documentation regarding the exact locations where the materials were placed. Some field observations can be made, but they cannot be fully relied upon due to the nature of the materials or the condition of the area (e.g., overgrown with dense vegetation). Some biased samples may be collected based on the limited knowledge of environmental conditions, but it would be necessary to supplement with statistical sampling of this area to evaluate in an unbiased manner whether *HOT SPOTS* are present.

General Recommendations

In general, the following recommendations are being made with regard to selection of sampling strategies for *FACILITY* characterization:

- A combination of sampling strategies should be considered for the purpose of *FACILITY* characterization.
- Biased sampling should be used whenever information is available with which to reliably bias sample locations.
- Systematic *RANDOM* sampling should be considered to supplement data obtained from most biased sampling programs. The number of samples and/or grid interval necessary to supplement biased sampling results will require use of professional judgment depending on the level of detail and accuracy of existing information used to bias sample locations.
- Systematic *RANDOM* sampling should also be conducted in areas believed to be unimpacted. Professional judgment will be necessary to determine the number of samples and/or the grid interval necessary to confirm that the area(s) meet cleanup criteria. For example, only a small number of samples may be needed if sufficiently detailed and accurate information exists to support that the area is unimpacted.

The *HOT SPOT* identification techniques described in Section 2.2.1.1 may be used to determine the required grid interval for finding a *HOT SPOT* of a given size and shape with a prespecified level of confidence. Section 2.2.1.2 provides formulas that can be used to determine a grid interval based on the size of the area to be sampled.

A benefit when using statistical sampling strategies, either alone or in conjunction with biased sampling, is that it may be appropriate to compare resulting data to Part 201 criteria using statistics. Furthermore, it may be appropriate to combine analytical results from statistical sampling with some or even all of the biased sampling results in a statistical analysis as described in Section 2.4.2 of this chapter. However, considerations summarized in Section 2.4.1 must first be addressed.

Once sampling has been conducted for the purpose of characterization, a judgment must be made as to whether a site has been adequately characterized. This judgment is generally subjective based upon the body of data collected and knowledge of site conditions. Furthermore, a *FACILITY* that was thought to be adequately characterized may need supplemental characterization based on data generated through subsequent sampling (e.g., when sampling for the purpose of estimating a *REPRESENTATIVE CONCENTRATION*, as described in Section 2.4.2.) This may be due to the discovery of unexpected results such as previously unidentified *HOT SPOTS*.

PROPOSALS for grid strategies other than those presented in this chapter may be submitted for DEQ review and approval on a case-by-case basis.

2.2.1.1 Sampling Grids for *HOT SPOT* Identification

Statistical tools are available that may be used to assist in the identification of *HOT SPOTS* during *FACILITY* characterization, particularly when there is limited knowledge about the location of *RELEASE* areas. These tools will be most useful to supplement biased sampling or for locating relatively large *HOT SPOTS.* In addition, these techniques may be useful for evaluating trade-offs between sampling costs and the probability of locating *HOT SPOTS* of a given size. For example, financial constraints may limit the number of samples to be collected from a property. The statistical methods for identifying *HOT SPOTS* described in this section can be used to evaluate the size of the *HOT SPOT* likely to be identified (or missed), given that a specified number of samples are collected along a sampling grid. Furthermore, when sampling is conducted using a grid system, these methods may give some perspective on the likelihood that *HOT SPOTS* exist which have not been found.

The methods described in this section may not be practical if the goal is to locate relatively small *HOT SPOTS* over large areas. Large numbers of samples may be necessary to locate small *HOT SPOTS* with an acceptable level of confidence. **It is not expected that these statistically-based tools will be used to identify small *HOT SPOTS* in this manner.**

Use of the statistical tools described in this section should not replace the use of professional judgment for characterization and/or locating *HOT SPOTS*.

Statistical Tools for Identifying *HOT SPOTS*

Statistical methods for identifying *HOT SPOTS* may be used to answer the following questions (Gilbert, 1987):

1. What size grid interval is necessary to locate a *HOT SPOT* with a specified level of confidence?
2. If a grid interval is pre-specified, what is the probability of locating a *HOT SPOT* of a specific size and shape?
3. What is the probability that a *HOT SPOT* exists when no *HOT SPOTS* were found by sampling on a grid?

Questions 2 and 3 may be of particular interest when sampling is conducted using the method described in Section 2.4.2, "*RANDOM* Sampling of *EXPOSURE UNITS*," since the number of samples (i.e., a minimum of nine) and the corresponding grid interval are predetermined. The size of a *HOT SPOT* likely to be identified (or missed) using this sampling method may be evaluated.

Procedures that can be used for *HOT SPOT* identification and detection are described in "Chapter 10: Locating *HOT SPOTS*" in Gilbert's book, "Statistical Methods for Environmental Pollution Monitoring" (1987). The methods outlined in Chapter 10 are based upon several important assumptions. These include:

- the *HOT SPOT* is circular or elliptical in shape
- samples are collected on a square, rectangular, or triangular grid
- contaminant concentration levels constituting a *HOT SPOT* are clearly defined (e.g., sufficiently above Part 201 criteria; see definition in Section 2.2.1)
- there are no measurement misclassification errors – that is, no errors are made in deciding when a *HOT SPOT* has been found

The method for identifying *HOT SPOTS* described by Gilbert does not incorporate a vertical component. For subsurface *HOT SPOTS*, the method targets the projection of the *HOT SPOT* to the surface. This is a limitation when applying this method for *FACILITY* characterization since many *RELEASE* areas may be present below the surface. Consequently, any sampling plan for identifying *HOT SPOTS* must also incorporate a vertical component.

A brief description of the method follows. For details, see Chapter 10 of Gilbert (1987). For the sake of simplicity, the square sampling grids described in Section 2.4.2, "*RANDOM* Sampling of *EXPOSURE UNITS*," are recommended. The equations and graphs in Gilbert (1987) provide the necessary tools to answer the three questions listed above.

The method for locating *HOT SPOTS* described by Gilbert generally involves specifying:

- the shape of the *HOT SPOT,*
- the allowable probability that a *HOT SPOT* will be missed,
- the spacing of the sampling grid,
- some combination of the above, depending on the objective of the analysis.

Then a graph and an equation are used to determine the quantity of interest. Overall, Gilbert's (1987) method is simple and easy to use, and it provides a sound, defensible technique for designing or evaluating a sampling program for *HOT SPOT* detection.

Example 2.2 Use of *HOT SPOT* Identification Techniques to Select a Grid Interval for Finding a Pre-Specified *HOT SPOT*

Suppose that we want to be able to detect a circular *HOT SPOT* with a radius of 10 ft (diameter of 20 ft) with 90% probability in a rectangular (80 x 125 ft) *EXPOSURE UNIT*. Using a square grid, what size of grid interval and approximately how many samples would be required to find this *HOT SPOT* with the specified probability?

Using Gilbert (1987), the grid interval should be about 18 ft. Consequently, approximately 31 samples would be required to cover this *EXPOSURE UNIT* using systematic sampling with a grid interval of 18 ft.

Example 2.3 Use of *HOT SPOT* Identification Techniques to Identify the Size of a *HOT SPOT* That Can Be Found Using a Pre-Specified Sampling Grid

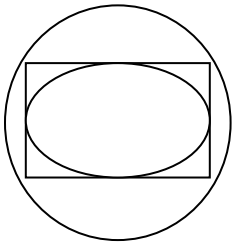
Now suppose that nine samples are to be collected from a square (300 x 300 ft) *EXPOSURE UNIT* using systematic sampling. The objective of the samples is to estimate a *REPRESENTATIVE CONCENTRATION* for comparison to criteria. Using the equation provided in the Section 2.4.2, "*RANDOM* Sampling of *EXPOSURE UNITS*," the approximate grid interval is 100 ft. using a square sampling grid. Assuming that a potential *HOT SPOT* is circular, what size *HOT SPOT* would be detected with 80% probability?

Given these specifications, the methods in Gilbert (1987) suggest that a circular *HOT SPOT* with a radius of 50 ft (diameter of 100 ft) would be detected 80% of the time using a 100 ft grid interval. A circular *HOT SPOT* with a radius of 70 ft (diameter of 140 ft) would be detected 100% of the time using a 100 ft grid interval.

It is not surprising that the grid intervals in the above examples are close in size to the intended target.

A limitation of the method described by Gilbert (1987) is that the *HOT SPOT* must be circular or elliptical in shape. But what about when the *HOT SPOT* is square or rectangular in shape? One option is to evaluate the objective considering a circle constructed around the hypothesized square or rectangular *HOT SPOT* and an ellipse fitting inside the *HOT SPOT* (Figure 2.1). Using the Gilbert (1987) method with the circle and the ellipse, bounds can be obtained for the quantity of interest.

Figure 2.1 Concentric Ellipse and Circle Bounding the Rectangular *HOT SPOT*



Example 2.4 Use of *HOT SPOT* Identification Techniques to Select a Grid Interval for Finding a Rectangular *HOT SPOT*

Suppose that you were designing a sampling plan for a 300 x 300 ft square site and wanted to find a 20 x 40 ft rectangular *HOT SPOT* with a probability of 80%. Using the methods in Gilbert (1987), a grid interval of 26.7 ft (approximately 126 systematic samples) is required to detect the small ellipse and an interval of 44.7 ft (approximately 45 systematic samples) is required to detect the larger circle with a probability of 80%. To find the rectangular *HOT SPOT*, the appropriate grid interval and number of samples lies somewhere between these bounds. The radius of the circle can be determined using the following equation:

$$Radius = \frac{\sqrt{w^2 + l^2}}{2}$$

where w is the width of the rectangle and l is the length of the rectangle.

Setting the Grid

After the grid interval is calculated, it is recommended that a scaled grid overlay be made to superimpose on a map of the area. A point (usually the southwest corner) should be designated as the (0,0) coordinate. The grid can then be adjusted to maximize sampling coverage. Some grid adjustment may be necessary for unusually shaped areas.

Variations on Basic Approach

When the goal is to identify *HOT SPOTS*, further *RANDOMIZATION* of sample locations as described in Section 2.2.1.2 is generally not appropriate. Grid stations must be equally spaced to be able to draw conclusions about the size of the *HOT SPOT* that can be identified.

Available Software for Identification of *HOT SPOTS*

Software tools are also available that can be used to assist in the design of sampling plans for *HOT SPOT* detection. Visual Sampling Plan (VSP) and Fully-Integrated Environmental Location Decision Support system (FIELDS) are two of these programs. VSP is a freeware downloadable program developed by Richard Gilbert and other staff of the Pacific Northwest National Laboratory and is available at http://vsp.pnnl.gov/. Once a site map and a sampling plan have been imported or generated, VSP has the capability of identifying the largest unsampled *HOT SPOT* that may be present. In addition, it can determine the number of samples needed to obtain a desired level of precision, the total cost of various sampling plans, and the locations that should be sampled based on *RANDOM* or systematic sampling.

The FIELDS program is also freeware, but the program disk must be requested. FIELDS offers many of the same sampling plan design capabilities (determining the number of samples, grid intervals, sample locations, and unsampled *HOT SPOT* sizes) with additional capabilities for spatial interpolation and modeling. However, ArcView (a Geographical Information System program) is required to run FIELDS. Because of this, FIELDS may be of limited utility for smaller-scale site assessments or for those without access to ArcView.

2.2.1.2 Sampling Grid Based on Size of Area to be Sampled

The equations and tables in this section provide a simple basis for establishing a grid system to facilitate unbiased selection of sampling points and sample coverage proportional to the area being sampled.

Basic Approach

This method for calculating grid intervals provides a grid point representation that is proportioned to the size of the area being sampled. The following equations provide grid interval estimates for small, medium and large sites, respectively. Small sites are defined as less than 1/4 acre (i.e., < 1/4 acre). Medium sized sites range from larger than 1/4 acre to three acres. Large sites are those which are more than three acres in size. Once a grid interval is determined, a grid system can established over the area to be sampled.

$$small\ \ site \qquad \frac{\sqrt{A/\pi}}{2} = GI$$

$$medium\ \ site \qquad \frac{\sqrt{A/\pi}}{4} = GI$$

$$large\ \ site \qquad \sqrt{\frac{A\pi}{SF}} = GI$$

where: A = area to be grid (ft^2)
GI = grid interval
SF = Site Factor, length of area to be grid (unitless)

To simplify this application, the following chart may be used based on an average size range of sites (one acre = 43,560 ft^2). The approximate grid ranges are provided as a quick check on numbers generated for specific sites using the above formulas.

Table 2.1 Approximate Grid Ranges Based on Size of Area to be Sampled

Acreage of Area to be Sampled	*Square Feet*	*≈Grid Interval Ranges*
up to 0.25 (small)	up to 10,890	0-29 ft
0.25-3.00 (medium)	10,890-130,680	15-50 ft
3.0 and over (large)	130,680 +	30 ft plus

Setting the Grid

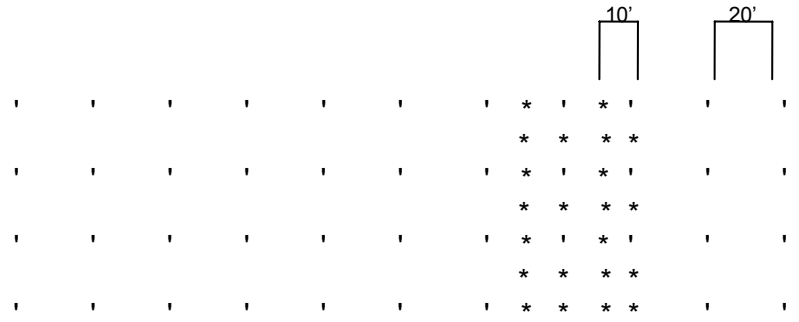
After the grid interval is calculated, it is recommended that a scaled grid overlay be made to superimpose on a map of the area. A point (usually the southwest corner) should be designated as the (0,0) coordinate. The grid can then be adjusted to maximize sampling coverage. Some grid adjustment may be necessary for unusually shaped areas.

Variations on Basic Approach

1. Subgridding

It may be warranted to apply grids with different intervals portions of the area to be sampled so that a proportional sampling can be focused on suspect areas (such as sumps, tank leak areas, etc.).

Example 2.5 Subgridding

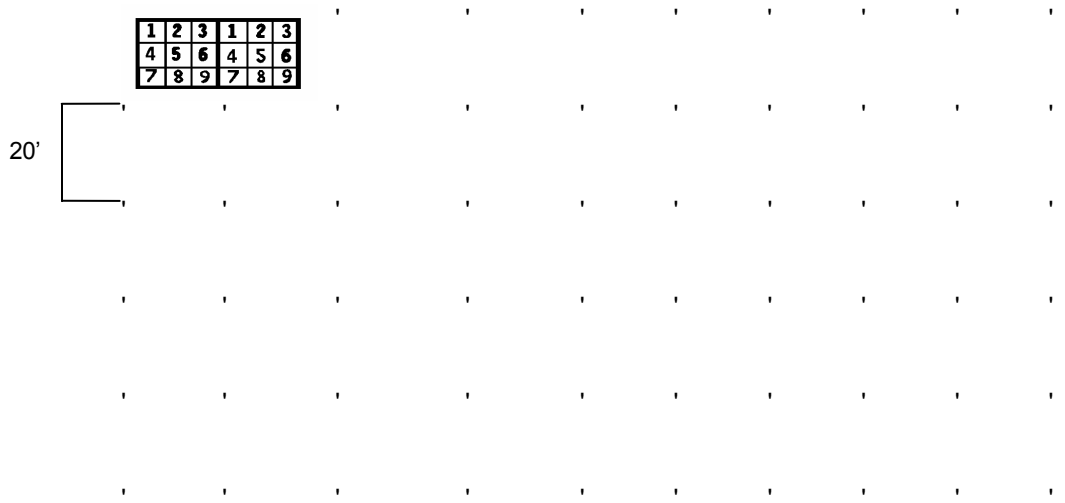


' = Area I Sample Station, 80' x 200', GI = 20'
* = Area II (subset of I) Sample Station, 30' x 50', GI = 10'

2. Further *RANDOMIZATION*

Sites that may have a patterned distribution of waste or contamination due to time sequence of filling, production sequences, or physical site conditions (i.e., furrows) may require a further *RANDOMIZATION* of sampling. In such cases, the following grid cell sampling format may be selected instead of using regular grid point stations. Each grid cell to be sampled may be divided into nine equal sized "subcells." Next, a *RANDOM* numbers table is used to select one of the nine subcells for sampling. The *RANDOM* numbers table can be used again to select a subcell for the next cell and so on.

Example 2.6 Further *RANDOMIZATION* Using Sampling Grids



Area = 120' x 200', GI = 20'

In the example above, a sampling grid was set up with grid point stations 20 ft apart using the appropriate formula. Two cells have been divided into nine subcells each to illustrate further *RANDOMIZATION*. Two *RANDOM* numbers were selected: 4 and 2. Samples should be collected from subcell #4 in the first cell and subcell #2 in the other cell. This process would be continued for all of the cells.

It would generally not be appropriate to apply this technique to the sampling grids described in Section 2.2.1.1. Because the goal of the sampling approach described in Section 2.2.1.1 is to identify *HOT SPOTS*, the grid stations must be equally spaced to be able to draw conclusions about the size of the *HOT SPOT* that can be identified.

2.2.2 *BACKGROUND*

Establishment of *FACILITY-SPECIFIC BACKGROUND* concentrations is described in Section 1.2.2. *FACILITY-SPECIFIC BACKGROUND* samples are not typically collected using statistical or probabilistic approaches. An effort is made to reflect the same natural conditions observed at a *FACILITY.* Consequently, *FACILITY-SPECIFIC BACKGROUND* data are somewhat biased. Although not described here, statistical or probabilistic methods could be incorporated into *FACILITY-SPECIFIC BACKGROUND* soil sampling. If multiple soil types or horizons are present, this could be accomplished through *RANDOM* sampling of each soil type or horizon independently.

2.3 VERIFICATION OF REMEDIATION

This section describes the use of statistical or probabilistic sampling strategies for the purpose of verifying remediation. When verifying remediation of medium- or large-sized areas, statistical sampling strategies are generally recommended. Medium-sized areas are generally defined as

areas ranging from 1/4 acre to three acres. Large areas are those which are larger than three acres.

For each type of remediation described below, statistical analyses for comparing verification data to Part 201 criteria may be appropriate if the data are generated using a statistical sampling approach. However, there are several key considerations which must first be addressed, as described in Section 2.4.1.

If a statistical analysis is used to compare verification data to Part 201 criteria, verification data from other areas should not generally be combined with data from remediated areas. In addition, verification of remediation should be demonstrated independently for each remediated area. If more than one area has been remediated (e.g., through excavation of soils), it is not appropriate to combine areas for the purpose of verifying remediation, regardless of the exposure pathway being evaluated. In the case of in situ or ex situ remediation, previous soil sample data should generally not be included with the new verification soil sample data for statistical analysis.

Compositing samples for verifying soil remediation is not acceptable without prior DEQ approval. When verifying a soil remediation is complete, contaminant concentrations will be low. Compositing may result in the contaminant concentrations not being representative of what remains in the soil. If concentrations are low, compositing may dilute the concentrations of a contaminant to below its threshold detection limit. Additionally, if contamination is indicated in a composited sample, the location of the contamination remains unknown.

2.3.1 Selecting Numbers and Locations of Verification Samples in Excavations

Verifying that contaminated soil is remediated by means of excavation requires collection of samples from the excavation bottom and sidewalls. It should be noted that "excavation" as used here refers only to that area excavated for remediation purposes and being verified to meet Part 201 cleanup criteria.

If sampling and statistical analysis indicate that Part 201 cleanup criteria have not been met, additional remediation will be required. If any portion of the soil in question appears to be causing the material to fail, the area above criteria may be identified through additional sampling and selectively removed. Subsequent sampling must be done to confirm that the remaining material meets Part 201 criteria.

Number of Samples

The number of samples to be collected will be determined based on application of a sampling grid to the area to be sampled. The method for establishing a grid interval described in Section 2.2.1.2 should generally be used. The “area” term in the formula used to determine the grid interval should reflect the total area of the excavation base and sidewalls.

A grid system should be established over the entire area of the excavation using the grid interval determined as above. The grid should extend over sidewalls and base. Grid placement may need to be adjusted to accommodate a minimum of at least one sample from each sidewall.

Sampling of Grid

If the use of statistics is appropriate for comparing soil verification data to Part 201 cleanup criteria, sampling of grids may include all of the grid stations or a phased subset of the total stations. A subset of grid stations may be created by assigning coordinates to all of the grid nodes and *RANDOMLY* selecting nodes for sampling using a *RANDOM* number generator or a *RANDOM* number table. A minimum of nine samples or 25% of the total number of grid points, whichever is larger, should be sampled to allow for a large enough data pool for statistical analysis. However, if statistics are to be used to compare verification data to Part 201 criteria, the considerations in Section 2.4.1 must also be addressed. If an excavation is divided into *EXPOSURE UNITS* to address a specific exposure pathway, a minimum of nine samples per *EXPOSURE UNIT* is necessary for statistical analysis. Consequently, it is advisable that extra samples also be collected and kept under proper chain of custody and storage procedures at the time of initial sampling to avoid an unnecessary return trip to the field.

Lambda Relationship

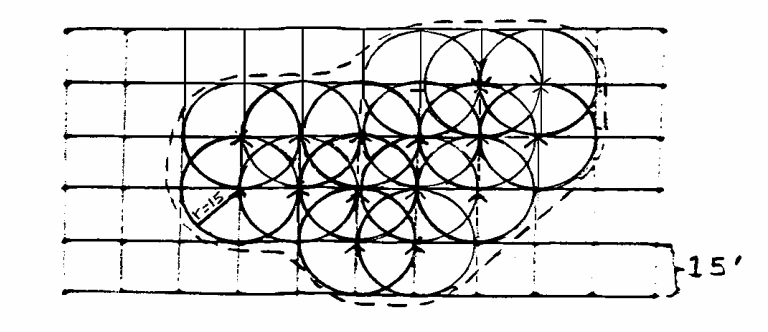
Methods for calculating the sample size requirements, including the Lambda Relationship, are presented in Section 3.2 of the tabbed section titled, “Statistical Methods.” These methods may be useful if an appropriately conducted statistical analysis results in a UCL for the mean that is above the cleanup criterion of interest, but the mean concentration is below. If this occurs, collection of additional samples may result in a lower UCL for the mean which is below the Part 201 criterion. The methods described in Section 3.2 can be used to estimate the number of additional samples that would be required, assuming that the data used in the original analysis were representative.

Grid Approach to Additional Remediation

One of the following two approaches may be used to help guide additional remediation through excavation. Selection of the appropriate method depends on whether verification samples were collected using a regular grid interval or if samples were further *RANDOMIZED* using subcells.

1. *Two-Dimensional Node Sampling Excavation Grid.* Verification sampling as described above will at times indicate that remediation is incomplete. Excavation of contaminated areas should be based on the established grid system interval. Where a subset of grid points has indicated that the entire area exceeds the cleanup, the nodes adjacent to the sampled nodes that are causing the exceedance should be sampled, and this process repeated until the "*HOT SPOTS*" requiring removal have been defined. The radius of excavation around the contaminated sample point(s) is equal to the grid interval (GI=r). Excavation depth is to the deepest point of contamination or to the depth where acceptable levels are anticipated. After excavation, the impacted point(s) must be resampled at their new elevations to verify that the area meets the selected cleanup criteria. If continued contamination is detected, the excavation format is repeated until a satisfactory result is obtained. Remediation of contaminated soil by excavation will be in accordance with the NREPA. The *PROPOSED* remedial action plan must be approved by the DEQ.

Example 2.7 Two-Dimensional Node Sampling Excavation Grid



GL = 150
A = 11,250
GI = 14.9

Sample
Station x
Contaminated Station
r = GI = 15 ft

2. *Two-Dimensional Subcell Sampling Excavation Grid*. The radius of excavation around a contaminated point may need to be adjusted to greater than the GI distance. This adjustment is due to the variable distances between sampling points.

2.3.2 Selecting Numbers and Locations of Soil Verification Samples for Ex Situ Remedies

The number of verification soil samples to be collected from a soil pile should be based on the volume of the soil pile. The table presented in Section 1.3.2 may be used for biased sampling.

If a statistical sampling strategy is to be used, a grid interval can be established for sampling of the soil pile. If the materials are heterogeneous and do not represent a single statistical distribution (e.g., a normal distribution with a mean of 3.6 and a standard deviation of 0.78), the sampling strategy described in Section 2.2.1.2 should be applied based on the size of a *HOT SPOT* to be identified. Since identification of *HOT SPOTS* is a two dimensional sampling technique, a vertical component must be added.

If it is demonstrated or reasonably concluded that concentrations of hazardous substances in the soil under consideration represent a single, homogeneous population, the effectiveness of ex situ soil remedies may be verified by three-dimensional *RANDOM* soil sampling. A minimum of nine samples should be collected from the waste pile if a statistical analysis is used for comparison to criteria. Additional samples may be necessary to adequately represent the variability of concentrations in the soil pile. Application of a sampling grid as described in Section 2.4 can be considered for placement of samples in the two-dimensional horizontal plane. A *RANDOM* numbers generator should be used to select the vertical sampling interval.

Fewer samples may be collected if hazardous substances concentrations are homogeneous; however, a point-by-point comparison to criteria must be made.

Certain ex situ remedies, such as bio-piles or aboveground vapor extraction, may be more amenable to statistical sampling strategies or batch sampling. Any *PROPOSED* sampling strategy for in situ or ex situ remedies should be pre-approved by the DEQ.

Statistical sampling strategies require discrete soil samples. Compositing of samples is not accepted without prior DEQ approval.

If ex situ treatment processes of contaminated soil or waste is used in the remediation, a sampling program for the process stream needs to be developed. The basis of this program is to get representative samples over time versus a spatial approach.

2.3.3 Selecting Numbers and Locations of Soil Verification Samples for In Situ Remedies

In situ verification soil sampling is required to evaluate the effectiveness of the remedy or to *PROPOSE* closure upon completion of an in situ soil corrective action (e.g., soil vapor extraction, bioventing, in situ bioremediation, and natural attenuation). The purpose of the in situ verification soil sampling is to demonstrate that the entire volume of contaminated soil is below Part 201 cleanup criteria. Because the in situ verification soil sampling is verifying remediation for a volume of soil, additional samples will be required beyond the number of sidewall and floor samples recommended above for excavations, as described below.

Number of Sample Locations

The number of samples to be collected will be determined based on application of a sampling grid over the area to be sampled. A grid interval can be established for sampling the volume of soil. If the materials are heterogeneous and do not represent a single statistical distribution (e.g., a normal distribution with a mean of 3.6 and a standard deviation of 0.78), the sampling strategies described in Sections 2.2.1.1 and 2.2.1.2 should be considered. Since these are two dimensional sampling techniques, a vertical component must be added.

However, if statistics are to be used to compare verification data to Part 201 criteria, the considerations in Section 2.4.1 must also be addressed. This may have an impact on the number of samples necessary to verify remediation. Fewer samples may be collected if hazardous substances concentrations are homogeneous; however, a point-by-point comparison to criteria must be made.

Grid placement may need to be adjusted to provide for a sufficient number of samples along the horizontal and vertical boundaries of the volume of soil that was remediated.

Determining Vertical Sampling Intervals for In Situ Verification Sampling

At least one sample should be collected from each five feet of the verification sample boring, with the exception of borings that are advanced through uncontaminated backfill or native soils. The five-foot interval may be subdivided into six-inch intervals, and an interval *RANDOMLY* selected for sampling.

The verification soil borings must extend at least as far as the known depth of the soil contamination. If a confining layer is determined to be the lower boundary of the contamination (as should have already been determined during the investigation phase), at least one soil sample should be collected from the top of the lower confining layer to verify this. If the confining layer is not the lower boundary of the contamination, then a sampling of this layer and below must be conducted in relation to the remediation activity.

Other Considerations

Partial dewatering of an aquifer can allow soil vapor extraction and/or bioventing systems to remediate the residual soil contamination below the water table. If the groundwater potentiometric surface is being lowered during remediation, then the verification soil samples should be collected while the soils in question are still dewatered. The groundwater dewatering system should then be discontinued and verification groundwater samples collected.

2.4 DEMONSTRATING COMPLIANCE WITH PART 201 CRITERIA USING STATISTICS

Sampling conducted for the purpose of identifying and characterizing *RELEASE* areas may not yield adequate data to estimate a *REPRESENTATIVE CONCENTRATION* (the 95% UCL for the mean) for comparison to Part 201 criteria. Therefore, once the nature and extent of contamination has been defined, it is necessary to identify and/or obtain data that will allow for appropriate comparison to cleanup criteria, if statistics are to be used. The goal of samples used to estimate a *REPRESENTATIVE CONCENTRATION* is to represent both exposures and hazardous substance concentrations in an appropriate *EXPOSURE UNIT*. Consequently, an *EXPOSURE UNIT* must first be identified that adequately represents exposures (e.g., a 1/4 acre *EXPOSURE UNIT* for evaluating compliance with generic residential soil direct contact criteria). Systematic *RANDOM* sampling may then be used to identify locations for collecting the minimum of nine samples necessary for statistical analysis.

Note that if all samples in an area are below cleanup criteria and the area is believed to be adequately characterized, the investigation for that area may be complete. A statistical analysis is not required. Adequate documentation of all sample locations must be provided based on sufficient knowledge of known or suspected *RELEASE* areas. A thorough justification must be documented for each sample location explaining the rationale used to select the location.

2.4.1 General Considerations When Demonstrating Compliance Using Statistics

Before assembling a data set and conducting a statistical analysis for comparison to criteria, it is important to give careful consideration to the following:

FACILITY Characterization

FACILITY characterization is a necessary first step before conducting an appropriate statistical analysis of *FACILITY* data for comparison to Part 201 cleanup criteria. Adequate knowledge of contaminant distribution and the presence of *HOT SPOTS* is essential.

Adequate *FACILITY* characterization is necessary due to assumptions underlying the statistical methods recommended by both the DEQ and the Environmental Protection Agency for comparing site data to cleanup criteria (i.e., 95% UCLs for the mean concentration). Adherence to these assumptions is necessary if an accurate statistical conclusion is to be drawn. One key assumption is that the data are independently and identically distributed (iid). For this assumption to be true, the following are generally necessary:

- Samples must be *independent* and representative of the area included in the analysis. In statistical terms, this means that the data were collected *RANDOMLY*.
- For the data to be identically distributed, each data point must have been drawn from the same *identical* statistical distribution (e.g., a normal distribution with a mean of 3.6 ppm and a standard deviation of 0.78 ppm). Data from a *HOT SPOT* area would be represented by a different statistical distribution than data from non-*HOT SPOT* areas. In other words, the mean concentration in a *HOT SPOT* area would be higher than in the non-*HOT SPOT* areas and the standard deviation would likely differ as well.

Consequently, adequate characterization and identification of *HOT SPOT* areas is necessary before an appropriate statistical analysis can be conducted.

Once defined, *HOT SPOTS* should not be included in a statistical analysis for comparison to most criteria. *HOT SPOTS* must be addressed separately. This is necessary to avoid combining data from different statistical distributions and violating the assumptions of the statistical methods. Furthermore, combining samples from *HOT SPOT* areas with samples from other areas of a property for statistical analysis will dilute the sample results that represent *HOT SPOTS*, potentially leaving unacceptable levels of hazardous substances in place. Specific recommendations for treatment of *HOT SPOTS* are provided in the Statistical Guidesheets for each of the pathways and closure categories (see tabbed section titled, "Statistical Guidesheets").

Applicability of Statistics

Before using statistics to compare *FACILITY* data to any Part 201 cleanup criterion, it is important to consider the applicability of statistics for demonstrating compliance with that criterion. Statistical Guidesheets have been developed to describe the extent to which statistical analysis of data may be relied upon to evaluate each exposure pathway and condition. At the top of each Statistical Guidesheet is an Applicability of Statistics Section which summarizes the primary factors to consider for that exposure pathway or condition. "YES," "Generally Not Practical (GNP)" or "NO" appear in a box to the right of the Applicability of Statistics heading to indicate the degree to which statistical analysis is appropriate.

Statistical Guidesheets categorized as "YES" indicate that use of statistics may be appropriate for the exposure pathway/condition and that sufficient data are likely to be available to calculate a *REPRESENTATIVE CONCENTRATION* for comparison to cleanup criteria. Statistical Guidesheets designated as "GNP" indicate that statistical applications may be appropriate but that data are not likely to be available and/or the complexities of the exposure pathway/condition make it difficult to derive a *REPRESENTATIVE CONCENTRATION* for comparison to cleanup criteria. Conditions for which no generic criteria have been developed (e.g., polluted soil runoff to surface water), are also designated as "GNP." Finally, the exposure pathway categorized as "NO" means that statistical analysis is not allowed due to an administrative rule requirement. This is true only for the drinking water pathway for which administrative rule 709(3) requires that criteria be met at every point in the affected aquifer.

Identification of an Appropriate Data Set for Statistical Analysis

Selecting the proper data set for a statistical analysis, if a statistical analysis is appropriate for the exposure pathway or condition, is an important step given the manner in which sampling data are typically obtained at sites. Section 2 of the Statistical Guidesheets addresses Selection of Data for Statistical Analysis.

All data gathered from *FACILITY* investigations may not be suitable for statistical comparison to cleanup criteria. Samples collected for the purpose of characterizing a *FACILITY* are typically biased, based on factors such as historical information, previous sampling, disposal practices, visual impacts, and aerial photos. Once the nature and extent of contamination has been defined, it is necessary to identify and/or obtain data that will allow for appropriate comparison to criteria. There are two primary considerations in determining if data sets are adequate. First, data sets must be obtained from locations that represent the exposure pathway or condition and the relevant land use category. For many of the exposure pathways *EXPOSURE UNITS* are defined to describe the area over which a person may be exposed to hazardous substances and data required for each *EXPOSURE UNIT*. Second, if statistics are used, data sets must contain a sufficient number of *RANDOMLY* located sample results to adequately represent hazardous substance concentrations and allow for proper statistical analysis and development

of *REPRESENTATIVE CONCENTRATIONS*. Therefore, additional sampling will often be required to support statistical analyses after the nature and extent of contamination has been defined. Although *RANDOM* samples are preferred for deriving a *REPRESENTATIVE CONCENTRATION*, previous sample results may be used on a *FACILITY*-specific basis. See further discussion of this issue in Section 2.4.2.

The appropriate data set for statistical analysis also depends on the size and variability of hazardous substance concentrations in the *EXPOSURE UNIT*. The size of the *EXPOSURE UNIT* varies between different exposure pathways and the land use category being considered. Generally, only data from one *EXPOSURE UNIT* may be used in each statistical analysis for comparison to cleanup criteria.

Section 2 of the Statistical Guidesheets also provides information related to unique aspects of the exposure pathway/condition that affect which data may be included in a statistical analysis for comparison to criteria. For example, only groundwater data from *GSI MONITORING WELLS* within the *AVERAGING AREA* may be used for statistical comparison to chronic mixing zone-based groundwater surface water interface (GSI) criteria.

Selecting the Appropriate Statistical Method for Comparison to Criteria

Once the applicability of statistics has been established and an appropriate data set identified, it is necessary to select the appropriate statistical method(s) for comparing those data to Part 201 criteria.

A 95% UCL for the mean should be utilized to compare *FACILITY* data to Part 201 criteria. Various methods are available for calculating UCLs for the mean concentration. Selection of the appropriate method requires an evaluation of the assumptions underlying each method. One of these assumptions is the statistical distribution of the data set (i.e., normal, lognormal, or neither). Consequently, each data set must be evaluated for the best-fitting statistical distribution. Chapter 1 of the tabbed section titled, “Statistical Methods” provides several techniques to accomplish this task. As described in Chapter 1, these techniques should be used in combination to best evaluate the statistical distribution.

Chapter 2 of the tabbed section titled, “Statistical Methods” provides techniques for identifying whether suspect data points are statistical outliers. Recommendations for treatment of outliers, once identified, are also provided in Chapter 2.

Methods for calculating UCLs for the mean concentration are provided in Chapter 3 of the tabbed section titled, “Statistical Methods.”

2.4.2 *RANDOM* Sampling of *EXPOSURE UNITS*

One of the most important factors that affect the quality of a statistical assessment of hazardous substances is sample design. Sample design simply refers to the methodology used to locate and collect samples. However, the conceptual simplicity of designing a sampling scheme belies its importance. Because most statistical methods require a *RANDOM* sample from the population under study, without a proper sampling design a *RANDOM* sample cannot be assured. Without a *RANDOM* sample, drawing accurate conclusions is difficult, if not impossible.

Sampling for the purpose of estimating a *REPRESENTATIVE CONCENTRATION* for comparison to Part 201 criteria should involve some form of *RANDOM* sampling within an *EXPOSURE UNIT.* Two methods for *RANDOM* sampling are described below. *RANDOM* sampling within an appropriate *EXPOSURE UNIT* will yield data which are representative of: 1) the exposure pathway or condition given the relevant land use category, and 2) concentrations of hazardous substances within the *EXPOSURE UNIT*.

Biased sampling strategies require discrete soil samples. Compositing samples is not accepted without prior DEQ approval.

2.4.2.1 Simple *RANDOM* Sampling

Simple *RANDOM* sampling is a common sampling design, particularly in applications other than environmental studies. This design consists of *RANDOMLY* selecting locations within a specified area (e.g., an *EXPOSURE UNIT*) and then collecting a sample at each selected location. Although simple *RANDOM* sampling does provide a *RANDOM* sample from the population, it can be somewhat inefficient and costly to implement.

Determining the *RANDOM* locations and subsequently locating them is a laborious task, possibly requiring a computer and a Global Positioning System (GPS). In addition, simple *RANDOM* sampling tends to unevenly sample the area under consideration. Some areas would likely contain several sample locations in close proximity, while other areas would remain unsampled. The uneven coverage that can result from simple *RANDOM* sampling is illustrated below.

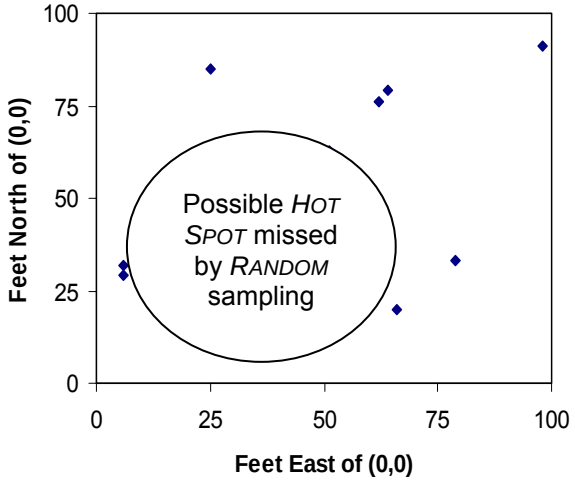
Example 2.8 Simple *RANDOM* Sampling

Figure 2.2 illustrates a sampling design where nine samples were collected *RANDOMLY* over a 100 ft x 100 ft area (approximately 1/4 acre). To locate each sample, a pair of *RANDOM* numbers between 0 and 100 was generated using the Microsoft Excel function:

=RANDBETWEEN(L,U)

where L is the lower number (set to 0 in this case) and U is the upper number (set to 100 in this case). The results for the first sample location were 5 and 27. Starting from the southwest corner of the *EXPOSURE UNIT*, this sample was located by moving 5 ft east and 27 ft north.

Figure 2.2 Simulated Simple *RANDOM* Sample of Nine Observations from a 100 ft x 100 ft (1/4 Acre) *EXPOSURE UNIT*.



Notice that several large areas are not sampled whereas other areas are sampled rather intensively. This is because in *RANDOM* sampling, each location in an area has an equal probability of being sampled, without regard to locations of other samples. Due to the uneven coverage associated with this *RANDOM* sampling design, the likelihood of detecting a *HOT SPOT*, if one exists, is relatively low. With increased sampling intensity (i.e., increasing the number of samples collected), more of the *EXPOSURE UNIT* would be sampled and hence coverage would be improved. However, because systematic *RANDOM* sampling (described below) is more efficient and results in better coverage with better *HOT SPOT* detection capabilities, it is generally superior to simple *RANDOM* sampling for a statistical assessment of hazardous substances.

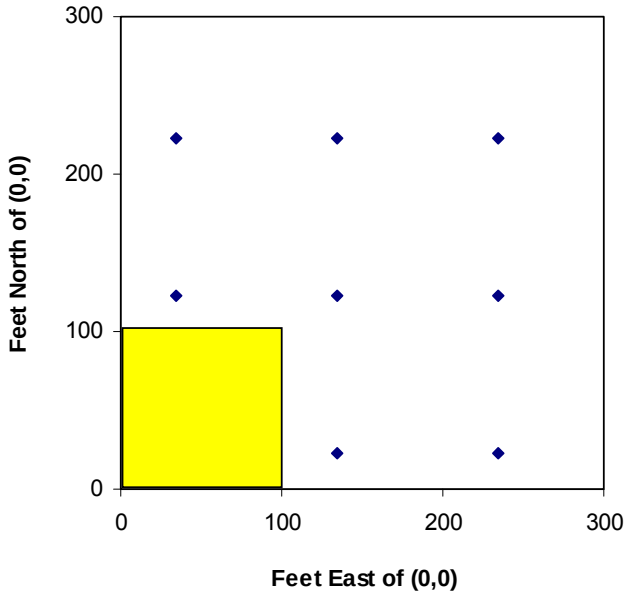
Note that we have made the assumption that the *FACILITY* has been adequately characterized prior to calculation of *REPRESENTATIVE CONCENTRATIONS*. Therefore, in most instances, *HOT SPOT* detection capabilities at this point should not be of major concern. However, because the approach described in the following section may serve both purposes of obtaining a *RANDOM* sample for estimation of a *REPRESENTATIVE CONCENTRATION* and *HOT SPOT* identification, this approach should be considered during the characterization stage in areas where no previous information is available to bias *FACILITY* characterization samples. Furthermore, to the extent that a *HOT SPOT* was missed in the characterization stage, this approach may help in the identification of remaining *HOT SPOTS*.

2.4.2.2 Systematic *RANDOM* Sampling

A preferable alternative to simple *RANDOM* sampling is systematic *RANDOM* sampling. This sampling design consists of dividing the total area to be sampled into subsections based on the number of samples to be collected (e.g., for nine samples, divide the total area into nine subsections) and *RANDOMLY* selecting a starting point within the first subsection. Subsequent sampling locations are then identified on a grid that is anchored at the starting point. The grid nodes represent locations to be sampled and all nodes are located based on the first *RANDOMLY*-selected location.

Figure 2.3 illustrates how systematic *RANDOM* sampling works. First, a 300 ft x 300 ft area was divided into nine subsections of equal area (100 ft x 100 ft). A point was *RANDOMLY* selected from the lower left cell of the *EXPOSURE UNIT*. Subsequent samples were identified systematically using a 100 ft grid extended from the first point.

Figure 2.3 Systematic *RANDOM* Sample of Nine Observations Collected from a 300 ft x 300 ft *EXPOSURE UNIT*.



The shaded area represents the cell from which the first sample was *RANDOMLY* selected.

The advantages of this design are numerous. First, it results in a *RANDOMIZED* sample from the population, thus satisfying the statistical requirements. Second, once the first location has been selected, locating the remaining sample locations is relatively straightforward and doesn't require a computer or GPS system. Third, because the coverage is fairly uniform, most of the *EXPOSURE UNIT* will be sampled and the likelihood of missing a large *HOT SPOT* is reduced. Furthermore, since sample locations are identified using a grid, statistical tools described in the tabbed section titled, "Identification and Consideration of *HOT SPOTS*," may be used to estimate the size of a *HOT SPOT* that might be identified (or missed) using this sampling approach. However, there is a danger that, if contamination occurs with some pattern, samples located on

a grid could systematically "miss" the contamination. If this is a concern, use of an unaligned grid (Gilbert, 1987, page 93) should be considered.

To determine the grid spacing, first determine the number of samples that are to be collected. The recommended minimum number is nine, based on statistical considerations only. Additional samples may be necessary to adequately represent spatial variability in the *EXPOSURE UNIT*. Next, use the following equation to determine an approximate grid interval:

$$\text{Grid Interval} = \sqrt{\frac{Area}{n}}$$

Where *Area* represents the total area of the *EXPOSURE UNIT* and *n* represents the number of samples that are to be collected.

The grid interval equation given above provides a rough approximation to a reasonable grid interval. The unique shape and size of the *EXPOSURE UNIT*, as well as the number of samples to be collected, will influence what the appropriate grid interval should be and where samples should be collected. The aim of systematic *RANDOM* sampling is to evenly cover the sampled area while collecting a *RANDOM* sample. Judgment must be used to decide on a sampling plan that is appropriate for individual *EXPOSURE UNITS*.

Example 2.9 Systematic *RANDOM* Sampling

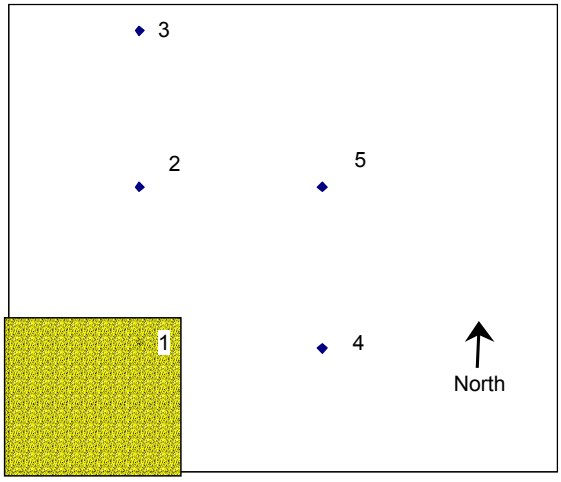
Figure 2.4 represents a square *EXPOSURE UNIT* of approximately two acres (i.e., 300 ft x 300 ft). Suppose that nine samples are to be collected. Using the above equation, the resulting grid interval is 100 ft. The *EXPOSURE UNIT* was divided into nine subsections of equal area (100 ft x 100 ft) and a sample location was *RANDOMLY* selected from the 100 ft x 100 ft cell in the lower left corner of the *EXPOSURE UNIT*. Based on the point selected, subsequent points are collected at the nodes of a grid with the grid interval equal to 100 ft.

The initial *RANDOM* sample location within the 100 x 100 ft cell in the southwest corner of the *EXPOSURE UNIT* was obtained as follows (which corner you start from is irrelevant, but for the sake of consistency, we recommend beginning in the southwest corner). First, generate two *RANDOM* numbers between 0 and 100 using the Microsoft Excel function:

=RANDBETWEEN(L,U)

where L is the lower number (set to 0 in this case) and U is the upper number (set to 100 in this case). The results were 80 and 94. Starting from the southwest corner of the *EXPOSURE UNIT*, move 80 ft east and 94 ft north to establish the *RANDOM* starting point within the southwest cell. The remaining eight sample locations are then positioned at the nodes of a grid with a 100 ft grid interval. For example, the second sample would be located 100 ft north of the first and the third would be located 200 ft north of the first. The fourth would be located 100 ft east of the first, and the fifth would be located 100 ft north of the fourth. This process would continue until all nine systematic *RANDOM* sample locations had been identified.

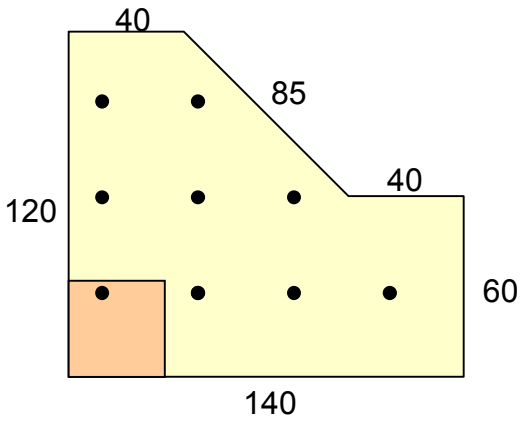
Figure 2.4 Systematic *RANDOM* Sampling of a Two Acre *EXPOSURE UNIT*



Example 2.10 Systematic *RANDOM* Sampling of an Odd-Shaped *EXPOSURE UNIT*

Figure 2.5 represents an odd-shaped *EXPOSURE UNIT* with the dimensions as listed (in feet). The first step is to determine the total area of the polygon, which is 12,600 ft^2. Suppose that nine samples need to be collected by systematic *RANDOM* sampling. Using the above equation, the approximate grid interval is 37 ft. To determine the *RANDOM* starting point, we generate two *RANDOM* numbers, 9 and 27. Starting in the lower-left corner of the polygon, we move nine ft east and 27 ft north to establish the first sample location. Subsequent samples are located on a grid anchored on the first point with a grid interval of 37 ft. If we denote the lower-left corner of the polygon as the (0,0) point on a (x, y) coordinate plane, the nine sample locations depicted are at (9,27), (9,64), (9,101), (46,27), (46,64), (46,101), (83,27), (83,64), and (120,27). Professional judgment may be used to increase the number of samples to be collected if nine samples do not appear to provide adequate coverage of an odd-shaped *EXPOSURE UNIT*.

Figure 2.5 Systematic *RANDOM* Sampling of an Odd-Shaped *EXPOSURE UNIT*



2.4.2.3 Three-Dimensional Sampling

There is often a need to sample a volume of soil rather than simply the surface soils. Sampling a volume of soil involves three-dimensional sampling. That is, rather than sampling in two dimensions only (e.g., North-South and East-West), a third dimension is incorporated (i.e., depth). In many cases, the vertical component is not sampled *RANDOMLY*, but rather based on knowledge of the underlying geology. For example, vertical sampling intervals may be selected so that samples are collected at an interface between two differing soil horizons.

The design of a three dimensional sampling plan (or any sampling plan for that matter) depends on how the population is defined. For example, if the population of concern is a fill layer from three-six feet in an *EXPOSURE UNIT*, then sampling surface soils in the *EXPOSURE UNIT* would be an improper sampling design. The sampling plan should be designed in such a way that representative samples from the intended population are collected.

If the goal is to use statistics to estimate a *REPRESENTATIVE CONCENTRATION* of hazardous substances in a defined layer, *RANDOM* sampling vertically as well as horizontally within the defined layer should be considered. That is, three-dimensional sampling should be considered in which systematic *RANDOM* sampling is completed in the horizontal dimension with an additional *RANDOM* component to sample depth. This approach will be most useful for evaluation of fill materials in which contamination is generally distributed throughout and differing soil horizons are not of a concern. **If initial *FACILITY* characterization shows that contamination is not homogeneous in the vertical dimension, this approach should not be used and sampling should be focused on depths of likely *RELEASES*.**

Using the methods outlined above, first define horizontal sampling locations. At each sample location, *RANDOMLY* select a depth for collecting the sample. The Microsoft Excel function shown below may be used to generate uniform *RANDOM* numbers between an upper and lower limit. This function is:

=RANDBETWEEN(L,U)

Where L is the lower limit and U is the upper limit for the *RANDOM* numbers. For example, if soils from 0-3 ft (i.e., 0-36 inches) are the intended population within an *EXPOSURE UNIT*, then this function can be used to generate a set of *RANDOM* depths from which to obtain samples. Since vertical sampling is often completed in six-inch intervals, the total depth of 36 inches can be divided into six intervals of six inches each. The above function can then be used to *RANDOMLY* select one of the six intervals (i.e., set L = 1 and U = 6) for sampling at each grid node.

An important caveat of three-dimensional sampling is the sample density (the number of samples per unit of volume or area). Sampling a volume (three dimensions) without increasing the total number of samples results in a lower sample density compared to sampling a two-dimensional area. If the sample density is too low, then the power to make statistical inferences is greatly reduced. Therefore, adequately sampling a volume will generally require more samples to be collected than would a two-dimensional sampling plan, particularly if the depth over which samples are to be collected is large.

For example, consider a two-dimensional systematic sampling plan where 10 samples from the top inch of soil are collected over a 25 x 30 ft area. This results in a sample density of approximately 0.16 samples/ft^3. Now contrast this with a three dimensional systematic sampling

plan where 10 samples from the top six inches of soil are collected over the same 25 x 30 ft area. This would result in a sample density of approximately 0.03 samples/ft^3. In fact, a total of 60 samples would need to be collected in the three-dimensional case to attain the same sample density as the two-dimensional case. This lower sample density in this three-dimensional sampling scenario reduces the relative power of the statistical inference about the sampled population.

2.4.2.4 Use of Site Characterization Data in Place of *RANDOM* Sample Locations

As previously stated, *RANDOM* sampling is important if accurate conclusions are to be drawn from a statistical analysis of data. *FACILITY* characterization data are typically biased, based on historical information such as previous sampling, past practices, visual impacts, and aerial photos. However, it may be impractical and cost prohibitive to sample every *EXPOSURE UNIT* from scratch using a *RANDOM* sampling design without use of existing data, where appropriate. Consequently, the following guidelines are recommended with regard to use of existing characterization data for a statistical analysis.

Divide the *EXPOSURE UNIT* into at least nine cells as described under Systematic *RANDOM* Sampling. (The number of cells is determined by the number of samples to be collected in the *EXPOSURE UNIT*.) If a single previous characterization sample location is present in a cell and the sample is representative of current conditions (e.g., the sample was collected from an area that has not been actively remediated), it may not be necessary to collect a new *RANDOM* sample from that cell. However, the sample must be comparable in terms of sampling and analytical methods and detection limits before making this determination and including the analytical result in the statistical analysis.

If more than one site characterization sample was collected from a cell, some judgment must be used to determine which data to include in the statistical analysis. In some cases, it will be appropriate to include all existing data from that cell in the statistical analysis; however, in some cases it will be appropriate to include only some of the data or to select one value to include in the statistical analysis. This determination must be made on a case-by-case basis.

The nature of the previous sampling is the main factor that needs to be considered when evaluating how much of the previous data can be included. For example, suppose that characterization samples present in a given cell are not clustered and are not associated with a *HOT SPOT*. Consider including each of the results in the statistical analysis because, presumably, the samples were collected independently and are representative of the overall variation in that area. However, if the characterization samples were highly clustered in a small area, and were collected for the purpose of investigating and/or confirming sample results in that limited area, the results may not represent the overall variability of concentrations in the *EXPOSURE UNIT.* Additional samples may be necessary. In this case, it would also be more appropriate to select a single value from the cluster of samples to avoid placing a disproportionately large weight on samples collected in a limited area.

It is also important to evaluate the extent to which the samples provide duplicative information. If sample analytical results are spatially correlated, the information provided by these samples is not independent, as required by the statistical methods presented in the S^3TM. Independence is necessary since, if sample results are correlated over space, the effective sample size is reduced. Each correlated sample does not provide as much “new” information about hazardous substance concentrations in an *EXPOSURE UNIT* because its value is partially determined by the value of adjacent observations.

Consequently, the following approach is recommended (alternate approaches may be acceptable on a case-by-case basis):

1. Divide each *EXPOSURE UNIT* into nine or more cells, as previously described.

2. Qualitatively evaluate the number of independent sample locations in each cell. Consider samples collected in a cluster to represent one sample location. At least one independent sample location is necessary in each cell if statistics are to be used to compare data from the *EXPOSURE UNIT* to criteria.

3. Select data for inclusion in the statistical analysis. Samples collected in a cluster: select the original sample result only for inclusion in the statistical analysis. That is, do not include any of the confirmatory sample results. Samples not collected in a cluster: consider including each sample in the statistical analysis. Note: Including more than one sample from a cell will result in more than nine samples from an *EXPOSURE UNIT* for statistical analysis, since at least one sample from each cell is necessary. Areas with spatially correlated concentrations above criteria (i.e., *HOT SPOTS*) must generally be excluded from the statistical analysis and addressed separately.

2.4.3 Comparison of *FACILITY* Data to *FACILITY-SPECIFIC BACKGROUND* Concentrations

When Part 201 criteria are established as *BACKGROUND* concentrations, the objective becomes to determine whether the *FACILITY* concentrations are significantly higher than *BACKGROUND* concentrations for a hazardous substance. To make this determination in most cases, *FACILITY* data will be compared to *FACILITY-SPECIFIC BACKGROUND* concentrations on a point-by-point basis. That is, concentrations of each hazardous substance in each *FACILITY* sample will be compared to directly to the *FACILITY-SPECIFIC BACKGROUND* concentration and individual exceedances will be noted. This will most often be the case when *FACILITY* samples are collected in a biased manner. However, it may also be necessary to compare *FACILITY* data collected using statistical sampling strategies to *FACILITY-SPECIFIC BACKGROUND* concentrations on a point-by-point basis.

If statistics are used to compare *FACILITY* data to *FACILITY-SPECIFIC BACKGROUND* data, a "two-sample test" may be used (i.e. a test that compares two data sets to each other). See Chapter 4 of the tabbed section titled, "Statistical Methods" for additional information. The appropriateness of using a statistical method to compare *FACILITY* data to *FACILITY-SPECIFIC BACKGROUND* data must be evaluated. This depends on: 1) the type of *BACKGROUND* being considered, 2) the manner in which *FACILITY* data were collected (i.e., using a biased or statistical approach), and 3) whether a statistical analysis of *FACILITY* data for comparison to *BACKGROUND* is appropriate. Statistical Guidesheets for the applicable pathways/conditions should be consulted to determine the applicability of statistics for comparing *FACILITY* data to Part 201 criteria and key considerations for selection of the appropriate data set(s). Recommendations provided in the Statistical Guidesheets apply to all Part 201 criteria, including *BACKGROUND*. A statistical analysis of *FACILITY* data for comparison to *BACKGROUND* will most likely be appropriate for pathways/conditions categorized as **YES**, or for those categorized as **GNP** for which a statistical analysis is demonstrated to be appropriate.

For additional information on statistical comparisons to *BACKGROUND*, see Section 2.2.2 of Sampling Strategies and Chapter 4 of the tabbed section titled, "Statistical Methods."

2.4.4 Recommended Summary Report Format

Soil Summary Reports for sites utilizing statistical sampling strategies must identify the number and location of samples and provide the justification of the sample locations selected (why and how). The Summary Report should contain site maps and cross-sections, drawn to scale, which depict the area and volume of contaminated soil; any remediation area(s); the locations of any air/fluid injection and/or extraction wells with their estimated zones of influence; the sampling grids; and the verification soil boring locations and vertical sampling intervals. The Summary Report should also include the calculations for determining the sampling grid intervals, a statement documenting the *RANDOM* sampling strategy utilized for selection of the sampling locations, the number of soil borings/samples and any statistical calculations used to evaluate the sample data.

The checklist below identifies items recommended to properly evaluate a closure certification. These items are not "absolutes." Other information or substitutions may be provided which technically justify and certify a "clean closure."

The verification report must include the following:

1. MAP(s) and CROSS SECTIONS
   Provide a scaled map of the investigated and remediated area (i.e. the estimated *RELEASE* area, or floor and walls of an excavation, or the vertical and horizontal area treated for in situ remediations, etc.) with sample locations identified. If a cross section is utilized to display the remediation activities and data, it should show the relation of key elevations, depict the stratigraphy, fractures, soil types, discolorations, unusual characteristics, possibly indicate the original *RELEASE* source location, sample locations/elevations, etc.

2. SAMPLE LOCATION RATIONALE
   - All sample locations (including *BACKGROUND* samples, *FACILITY* samples, and/or verification samples)
   - Sample depths
   - Sample collection procedures
   - Basis of sampling biases (where used) and the rationale used for collecting each sample (e.g., clay fractures, discolored soil, location of leak in tank)

3. DATA ANALYSES
   - Analytical parameters
   - Analytical methods used
   - Method detection limits
   - Laboratory Quality Assurance/Quality Control
   - Summary of decontamination procedures

4. STATISTICAL ANALYSES
   - Lab results/data tabulation
   - Complete statistical calculations as described in the tabbed section titled, “Statistical Methods”
   - If considered, development of *BACKGROUND* concentrations and/or statistical comparisons to *BACKGROUND* as described in Chapter 4 of the tabbed section titled, “Statistical Methods”

- Narrative explanation of all statistical calculations completed using *FACILITY* and/or *BACKGROUND* concentrations
- Comparisons of *FACILITY* data to cleanup criteria and/or *BACKGROUND* (either point-by-point or statistical)
- Completed worksheet for each statistical comparison (see the tabbed section titled, "Statistical Analysis Worksheets")

5. CONCLUSIONS
   This portion of the report should include a summary of activities and final conclusions, accounting for the work and testing completed and how completed activity(ies) fit in with the site-wide remediation plan (i.e. land use issues, possible closure requirements, whether there is a Remedial Action Plan, resumption of operations, etc.)

2.5 WASTE CHARACTERIZATION

Characterization of wastes for the purpose of disposal must often be addressed at Part 201 *FACILITIES*. The regulatory context for waste characterization is different than the context described in previous sections of this chapter, however. Sections 2.1 through 2.4 describe sampling and analysis of data for the purpose of demonstrating compliance under Part 201. Waste characterization is regulated under Parts 111 and 115. Consequently, sampling strategies and statistical analysis of data for this purpose have been described in a separate tabbed section titled, "Waste Characterization."

SUMMARY

Selection of a sampling plan to collect environmental samples is a complex, multifaceted, and multi-phased problem. As pointed out during the previous discussions of sampling strategies, the ***goal*** of any sampling plan is to collect samples that represent the environmental media and conditions being defined.

The beginning point is usually a conceptual model of the environmental conditions that exist at a property or *FACILITY* based on historical records, previous sampling, or site reviews. An evaluation of the completeness of the conceptual model is made to determine if existing information allows a reasonable model or if further characterization is needed to conceptualize the environmental conditions at the property or *FACILITY*.

If additional sampling is to be conducted, an objective should be set for the sampling plan (e.g., *FACILITY* characterization, identification of *RELEASE* areas, verification of remediation, comparison to regulatory criteria, waste characterization). This plan may involve a combination of sampling techniques (i.e., biased and/or statistical). The sampling plan should be guided by answering "why, what, when, where, and how" to sample. A continuous and sequential review and evaluation of the resulting data should be made to determine if the goal of the sampling plan has been met. Rarely is this sequence a straightforward, single-pathway, or simple analysis. Each sample as it is collected, analyzed, and evaluated may change the conceptual model and the overall sampling strategy. For example, identification of a previously unknown *HOT SPOT* may lead back to further characterization.

As new data become available, an iterative process should be conducted to continuously evaluate whether the data make sense in light of existing data and the conceptual model of the environmental conditions and whether characterization is complete.

The following example illustrates the iterative nature of this process and use of a combination of sampling techniques.

1) A site being investigated has a wealth of existing data (e.g., existing sampling locations and analytical results, documented site history, detailed and accurate information on operational procedures and equipment location). Therefore, additional site characterization will be completed using a biased sampling approach based on known conditions.
2) Sample results indicate that concentrations of one or more hazardous substances are highly elevated at a sample location. It must be decided whether to further characterize at this location by:
   a. continuing biased sampling, or
   b. initiating a statistical sampling plan.

The conceptual model of environmental conditions had been incomplete. To decide on a next step, it is necessary to evaluate why an unexpectedly high concentration was present at the sample location. Was it caused by a discrete release that could be documented as a result of further research? If so, biased sampling may be useful to focus on that location to identify the nature and extent of contamination. If not, it must be concluded that high concentrations may be present at more locations. If no reliable information is available with which to bias additional sampling, a statistical sampling strategy should be used to better characterize the area.

Summary

The decision was made to redirect the sampling plan to use a statistical sampling approach. Although some additional areas with elevated concentrations were identified as a result, none were confirmed to be *HOT SPOTS*. Biased samples were collected by stepping out around each elevated location to make this determination.

The next step is to make a determination on compliance with cleanup criteria. Since locations are present at which criteria are exceeded but none of these locations represented *HOT SPOTS*, it may be appropriate to consider a statistical analysis for comparison to criteria. However, before proceeding it is necessary to first evaluate several key considerations including the applicability of statistics for the exposure pathway(s) being evaluated, adequacy of characterization, and selection of the appropriate data set to represent exposures and hazardous substance concentrations in an appropriate exposure area. These concepts are addressed throughout Sampling Strategies (particularly Section 2.4.1) as well as in the tabbed section titled, "Statistical Guidesheets."

PART 201 STATISTICAL EVALUATION GUIDESHEETS

LIST OF PART 201 STATISTICAL EVALUATION GUIDESHEETS

A. Abandoned Substances Not Yet Dispersed and Free Phase Liquid
B. Soil: Contaminated Soil Runoff to Surface Waters
C. Surface Water Sediment: Aquatic Flora/Fauna/Food Chain Hazards and Aesthetics
D. Acute Toxicity and Physical Hazards: Acute Inhalation Toxicity and Flammability/ Explosivity, Corrosivity, Ignitability, and Reactivity
E. Ecological and Aesthetic Impacts: Terrestrial Flora, Fauna, Food Chain, Aesthetic or Other Impacts
F. Asbestos Containing Materials: Asbestos

GROUNDWATER

1. Generic Residential and Commercial I Drinking Water Criteria (DWC)
2. Generic Commercial II, III, IV and Industrial Drinking Water Criteria (DWC)
3. Generic and Mixing Zone-Based Groundwater Surface Water Interface (GSI) Criteria
4. Generic Residential and Commercial I Groundwater Volatilization to Indoor Air Inhalation Criteria (GVIIC)
5. Generic Commercial II, III, IV and Industrial Groundwater Volatilization to Indoor Air Inhalation Criteria (GVIIC)
6. Generic Groundwater Contact Criteria (GCC)
7. Water Solubility
8. Generic Screening Levels for Flammability and Explosivity
9. Generic Acute Inhalation Toxicity Screening Levels

SOIL

10. Soil Background
11. Generic Soil Criteria Protective of Residential and Commercial I Drinking Water
12. Soil Criteria Protective of the Groundwater Surface Water Interface (GSI)
13. Generic Soil Criteria Protective for Groundwater Contact
14. Generic Residential and Commercial I Soil Volatilization to Indoor Air Inhalation Criteria (SVIIC)

15.-17. Generic Residential and Commercial I Infinite and Finite Volatile Soil Inhalation Criteria (VSIC) for Ambient Air

18. Generic Residential and Commercial I Particulate Soil Inhalation Criteria (PSIC) for Ambient Air
19. Generic Residential and Commercial I Direct Contact Criteria (DCC)
20. Generic Soil Saturation (CSAT) Screening Levels
21. Generic Soil Criteria Protective of Commercial II, III, IV and Industrial Drinking Water
22. Generic Commercial II, III, IV and Industrial Soil Volatilization to Indoor Air Inhalation Criteria (SVIIC)

23.-25. Generic Commercial II, III, IV and Industrial Infinite Source Volatile Soil Inhalation Criteria (VSIC) for Ambient Air

26. Generic Commercial II, III, IV and Industrial Particulate Soil Inhalation Criteria (PSIC) for Ambient Air

27.-29. Generic Industrial and Commercial II, III, IV Direct Contact Criteria (DCC)

INTRODUCTION TO PART 201 STATISTICAL EVALUATION GUIDESHEETS

Statistical Guidesheets are lettered or numbered to correspond with the Criteria Application Guidesheets. Words that are in capital letters and italicized are defined terms that are presented in the tabbed section titled, "Acronyms / Glossary." Bullets presented as ★ are used to highlight considerations that are unique to the exposure pathway or condition.

The Statistical Guidesheets have been organized into sections to focus attention to the key considerations for each purpose for evaluating data. Section 1 of the Statistical Guidesheet addresses the use of statistical analysis for determining if a property is a *"FACILITY."* Section 2 identifies the key factors to consider when selecting data to include in a statistical analysis for the purpose of deriving a *REPRESENTATIVE CONCENTRATION* for comparison to cleanup criteria. Section 3 highlights the factors to consider when making comparison to the cleanup criteria, and Section 4 specifies the important considerations when using statistical analyses to demonstrate a verification of remediation or closure.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR **SOIL AND GROUNDWATER** DATA	Statistical Guidesheet A
ABANDONED SUBSTANCES NOT YET DISPERSED AND FREE PHASE LIQUID	
May assist in evaluation of condition(s):	1
Applicability of Statistics	**GNP**

Statistics are generally not practical as a tool for assessing this condition because source control evaluations will generally be conducted on a qualitative basis.

Key Considerations:		
	Section 1	**Facility Determination**
		★ The determination that property is a *FACILITY* is generally based on data which show that one or more generic residential cleanup criterion is exceeded. Information that documents the presence of abandoned hazardous substances which are not yet dispersed, or the presence of free phase liquid hazardous substances that have been *RELEASED* is also potentially sufficient to support a conclusion that property is a *FACILITY*. Consult your supervisor for guidance if necessary. Since *FACILITY* determinations that are based on the presence of abandoned sources or free phase liquids are generally not based on review of laboratory data, statistics are not expected to be relevant to those *FACILITY* determinations.
	Section 2	**Selection of Data For Statistical Analysis**
		• Not applicable - see Section 3.
	Section 3	**Risk Analysis – Comparison to Criteria**
		★ Since source control evaluations will generally be conducted on a qualitative basis (i.e., not based on rigorous comparison of *FACILITY* data to cleanup criteria or another value), statistics are not expected to be necessary.
	Section 4	**Verification of Remediation or Closure**
		• Not applicable.

Additional Information:	Criteria Application Guidesheet A and Appendix A (Part 201 Cleanup Criteria Training Materials: Source Control Obligations for Part 201 Facilities.)
Recommended Statistical Methods for Comparison to Criteria:	Not applicable.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR SOIL DATA	Statistical Guidesheet B
CONTAMINATED SOIL RUNOFF TO SURFACE WATERS	
May assist in evaluation of condition(s):	12
Applicability of Statistics	**GNP**
Statistics are generally not practical as a tool for assessing this condition because there are no generic cleanup criteria.	

Key Considerations:	**Section 1**	**Facility Determination**
		• The determination that property is a *FACILITY* is generally based on data which show that one or more generic residential cleanup criterion is exceeded. Since there are not generic cleanup criteria available for this condition, *FACILITY* determinations will not generally be based on this condition. If you are evaluating property where you suspect problems with this condition and no data are available to demonstrate that the property is a *FACILITY* for other reasons, consult your supervisor for guidance.
	Section 2	**Selection of Data For Statistical Analysis**
		• Not applicable - see Section 3.
	Section 3	**Risk Analysis – Comparison to Criteria**
		• Since there are no generic cleanup criteria available for this condition, statistical analysis of data is not generally expected to be used for risk analysis.
	Section 4	**Verification of Remediation or Closure**
		• Since there are no generic cleanup criteria available for this condition, statistical analysis of data is not generally expected to be used for verification of remediation or closure.

Additional Information:	Criteria Application Guidesheet B
Recommended Statistical Methods for Comparison to Criteria:	The statistical method for comparing *FACILITY* data to criteria will be determined on a case-by-case basis.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR SURFACE WATER SEDIMENT DATA	Statistical Guidesheet C
AQUATIC FLORA/FAUNA/FOOD CHAIN HAZARDS AND AESTHETICS	
May assist in evaluation of condition(s):	13
Applicability of Statistics	**GNP**

Statistics are generally not practical as a tool for initially assessing this condition because there are no generic sediment cleanup criteria. If the condition is determined to require response activity and site-specific criteria are developed, statistical evaluation of data may be possible. See Sections 2 and 3 below.

Key Considerations:

Section 1

Facility Determination

★ The determination that property is a *FACILITY* is generally based on data which show that one or more generic residential cleanup criterion is exceeded. Since there are no generic cleanup criteria available for this condition, *FACILITY* determinations using numerical data will not generally be based on this condition. However, site-specific sediment cleanup criteria may be developed for a *FACILITY* determination and Section 20a(17) allows for a qualitative *FACILITY* determination based on unacceptable risk to surface water and sediment. If you are evaluating property where you suspect problems with this condition and no data are available to demonstrate that the property is a *FACILITY* for other reasons, consult your supervisor for guidance.

Section 2

Selection of Data For Statistical Analysis

★ Generic cleanup criteria are not available for this condition; all sediment cleanup criteria are developed on a site-specific basis. This statistical guidesheet provides information on selecting data for comparison to site-specific criteria when available.

- Samples collected for the purpose of characterizing a *FACILITY* are typically biased, based on factors such as historical information, previous sampling, disposal practices, visual impacts, and aerial photos. Once the nature and extent of contamination has been defined, it is necessary to identify and/or obtain data that will allow for appropriate comparison to criteria. There are two primary considerations in determining if data sets are adequate. First, data sets must be obtained from locations that are consistent with the exposure assumptions for the relevant land use scenario. Second, if statistics are used, data sets must contain a sufficient number of *RANDOMLY* located sample results to allow for proper statistical analysis and development of *REPRESENTATIVE CONCENTRATIONS*. Therefore, additional sampling to develop *REPRESENTATIVE CONCENTRATIONS* will often be required after the nature and extent of contamination have been defined. Some characterization data may be used in the development of a *REPRESENTATIVE CONCENTRATION* as described in Section 2.4.2 of the tabbed section titled, "Sampling Strategies."

- A statistical analysis of soil data should be completed only if the nature and extent of contamination, including any *HOT SPOTS*, has been adequately defined.

	Section 2: (Continued)	• It is not appropriate to combine samples from *HOT SPOT* areas with samples from other areas of a property for statistical analysis. This is necessary to avoid averaging or diluting the samples that represent *HOT SPOTS*. *HOT SPOTS* must be addressed separately. See Section 2.2.2.1 of the tabbed section titled, "Sampling Strategies." ★ The selection of sediment characterization data that are appropriate for statistical analysis will depend on the exposures or other impacts that are the basis for the sediment cleanup criteria. See Guidesheet C in the Part 201 Cleanup Criteria Training Materials and Rule 717(5)(a) to (l) for information about the factors that must be considered in establishing sediment cleanup criteria.
	Section 3	**Risk Analysis – Comparison to Criteria** ★ Cleanup criteria for contaminated sediments will be established by the department, if necessary, based on the factors described in Rule 717(5)(a) to (l). The appropriateness of statistics as a tool for determining compliance will depend on which of the factors in that rule were used as the basis for each site-specific criterion (e.g., if adverse aesthetics is the basis for a sediment cleanup criterion, statistics may not be applicable). • If DEQ approval of a response activity is being sought, a *PROPOSAL* for a statistical analysis must be submitted to the DEQ for approval to assure that data needs and/or complexities of the pathway are addressed. *PROPOSALS* for the use of statistics must include a justification that relates the *PROPOSAL* to the basis for the cleanup criteria (e.g., mitigating degradation of benthos, or eliminating fish consumption restrictions).
	Section 4	**Verification of Remediation or Closure** ★ Cleanup criteria for contaminated sediments will be established by the Department, if necessary, based on the factors described in Rule 717(5)(a) to (l). The appropriateness of statistics as a tool for determining the adequacy of remedial actions will depend on which of the factors in that rule were used as the basis for each site-specific criterion (e.g., if adverse aesthetics is the basis for a sediment cleanup criterion, statistics may not be applicable). ★ If DEQ approval of a response activity is being sought, a *PROPOSAL* for a statistical analysis must be submitted to the DEQ for approval to assure that data needs and/or complexities of the pathway are addressed. *PROPOSALS* for use of statistics to evaluate sediment data for verifying remediation or closure must include a justification that relates the *PROPOSAL* to the basis for the cleanup criteria (e.g., mitigating degradation of benthos, or eliminating fish consumption restrictions).

Additional Information:	Criteria Application Guidesheet C
Recommended Statistical Methods for Comparison to Criteria:	The statistical method for comparing *FACILITY* data to criteria will be determined on a case-by-case basis.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR ACUTE TOXICITY AND PHYSICAL HAZARDS	**Statistical Guidesheet D**

ACUTE INHALATION TOXICITY AND FLAMABILITY/EXPOLSIVITY, CORROSIVITY, IGNITABILITY, AND REACTIVITY

May assist in evaluation of condition(s):	14
Applicability of Statistics	**GNP**

Statistics are generally not practical as a tool for assessing this condition because it deals with acute risks and any exceedance of screening levels requires further consideration.

Key Considerations:		
	Section 1	**Facility Determination** • The determination that property is a *FACILITY* is generally based on data which show that one or more generic residential cleanup criterion is exceeded. Since there are no generic cleanup criteria available for this condition, *FACILITY* determinations will not generally be based on this condition. If you are evaluating property where you suspect problems with this condition and no data are available to demonstrate that the property is a *FACILITY* for other reasons, consult your supervisor for guidance.
	Section 2	**Selection of Data For Statistical Analysis** • Not applicable – see Section 3.
	Section 3	**Risk Analysis – Comparison to Criteria** ★ Since this condition deals with acute risks, any exceedance of flammability/explosivity or acute inhalation screening levels requires further consideration. See Statistical Guidesheets 8 and 9 for additional discussion about application of screening values for acute effects. • Statistical treatment of data is not expected to be a practical tool for making decisions about the need for response activity related to this condition. • Professional judgment will be required to determine the significance of any data that relates to this condition. The quantity of the hazardous substance that is present above potential levels of concern is a factor that determines whether there may be an unacceptable risk.
	Section 4	**Verification of Remediation or Closure** • See Section 3.

Additional Information:	Statistical Guidesheets 8 and 9; Criteria Application Guidesheets D, 8 and 9.
Recommended Statistical Methods for Comparison to Criteria:	The statistical method for comparing *FACILITY* data to criteria will be determined on a case-by-case basis.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR **ECOLOGICAL AND AESTHETIC IMPACTS**	Statistical Guidesheet **E**

TERRESTIAL FLORA, FAUNA, FOOD CHAIN, AESTHETIC OR OTHER IMPACTS

May assist in evaluation of condition(s):	15
Applicability of Statistics	**GNP**

Statistics are generally not practical as a tool for assessing this condition because there are no generic cleanup criteria.

Key Considerations:		
	Section 1	**Facility Determination**
		• The determination that property is a *FACILITY* is generally based on data which show that one or more generic residential cleanup criterion is exceeded. Since there are no generic cleanup criteria available for this condition, *FACILITY* determinations will not generally be based on this condition. If you are evaluating property where you suspect problems with this condition and no data are available to demonstrate that the property is a *FACILITY* for other reasons, consult your supervisor for guidance.
	Section 2	**Selection of Data For Statistical Analysis**
		• Not applicable - see Section 3.
	Section 3	**Risk Analysis – Comparison to Criteria**
		• Since there are no generic cleanup criteria available for this condition, statistical analysis of data is not generally expected to be used for risk analysis.
	Section 4	**Verification of Remediation or Closure**
		• Since there are no generic cleanup criteria available for this condition, statistical analysis of data is not generally expected to be used for verification of remediation or closure.

Additional Information:	Criteria Application Guidesheet E
Recommended Statistical Methods for Comparison to Criteria:	The statistical method for comparing *FACILITY* data to criteria will be determined on a case-by-case basis.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR CONTROL OF **ASBESTOS CONTAINING MATERIALS**	Statistical Guidesheet **F**

ASBESTOS

May assist in evaluation of condition(s):	2, 6, 7, 12
Applicability of Statistics	**Pathway Dependent**

See Applicability of Statistics discussion on Statistical Guidesheet for relevant exposure pathway.

Key Considerations:		
	Section 1	**Facility Determination**
		• A *FACILITY* determination based on the presence of asbestos would generally depend on an exceedance of a generic residential cleanup criterion (e.g., drinking water or particulate soil inhalation). See relevant exposure pathway statistical guidesheets for further guidance on making *FACILITY* determinations. Also see Statistical Guidesheet A for discussion of the ways in which abandoned substances that are not yet dispersed may constitute a *FACILITY*.
	Section 2	**Selection of Data For Statistical Analysis**
		• See statistical guidesheets for relevant exposure pathways.
	Section 3	**Risk Analysis – Comparison to Criteria**
		• See statistical guidesheets for relevant exposure pathways.
	Section 4	**Verification of Remediation or Closure**
		• See statistical guidesheets for relevant exposure pathways.

Additional Information:	Statistical Guidesheets 1, 2, 18, and 26; Criteria Application Guidesheets 1, 2, 18 and 26.
Recommended Statistical Methods for Comparison to Criteria:	See statistical guidesheets for relevant exposure pathways.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR **GROUNDWATER** DATA	Statistical Guidesheet 1
GENERIC RESIDENTIAL AND COMMERCIAL I DRINKING WATER CRITERIA (DWC)	
May assist in evaluation of condition(s):	2
Applicability of Statistics	**NO**

Statistics are not applicable for assessing this exposure pathway because Rule 709(3) states that the point of exposure is presumed to be any point in the affected aquifer. As a result, cleanup criteria must be met at all points.

Key Considerations:		
	Section 1	**Facility Determination**
		• For the purposes of a BEA or initial *FACILITY* determination, property may be classified as a *FACILITY* if one or more samples contain concentrations above generic residential criteria or *BACKGROUND* concentrations, whichever is greater, provided that there is not a greater body of evidence that the property is not a *FACILITY*. For purposes other than *FACILITY* determination (e.g., remediation and/or closure), additional data will likely be required.
	Section 2	**Selection of Data For Statistical Analysis**
		• Not applicable – see Section 3.
	Section 3	**Risk Analysis – Comparison to Criteria**
		★ Statistical analysis of *FACILITY* groundwater concentrations for comparison to criteria (either across well locations or over time in an individual well) is not acceptable. Since the point of exposure is presumed to be any point in the affected aquifer [Rule 709(3)], groundwater drinking water criteria must be met at each point in an aquifer. Therefore, evaluation of groundwater concentrations must be completed on a point-by-point basis* (i.e., each concentration at a given time and location must be compared individually to criteria). • If *BACKGROUND* concentrations are greater than criteria for naturally occurring substances, groundwater concentrations may be compared to *BACKGROUND* concentrations. If comparison is made to *BACKGROUND* the comparison must be completed on a point-by-point basis.* See Statistical Guidesheet 10 and Chapter 4 of the tabbed section titled, "Statistical Methods." ★ Statistical analysis of groundwater concentrations over time in an individual well will not be allowed for comparison to criteria or *BACKGROUND*.
	Section 4	**Verification of Remediation or Closure**
		• **No Action Needed**: If the data evaluation completed under Section 3 demonstrates that there are no exceedances of cleanup criteria, no remedial action is required for this pathway and consequently no additional sampling or data analysis is required under Section 4.

	Section 4: (Continued)	• **In situ/Ex situ Treatment**: Plans for verifying remediation or closure must be made on a case-by-case basis and must demonstrate how treatment is effective in meeting cleanup criteria. To demonstrate verification of remediation or closure, concentrations in groundwater must meet criteria during a specified number of consecutive sampling events. The number of consecutive sampling events must be selected on a case-by-case basis to reflect seasonal variation in groundwater quality, flow rates, and initial distribution of contamination in groundwater. Ordinarily, this demonstration should be made using data from at least one year of quarterly sampling. • **Containment**: Generally groundwater sampling used to verify a groundwater containment remedy will be done at the perimeter of the containment system. Statistical analysis is not allowed for reasons described in Section 3. This verification will be an ongoing part of the remedy as long as hazardous substances are present above criteria. • Comparisons to criteria or *BACKGROUND* must be made on a point-by-point basis.* See Section 3.
Additional Information:		Criteria Application Guidesheet 1
Recommended Statistical Methods for Comparison to Criteria:		Not applicable.

*Professional judgment is required to interpret the significance of exceedances that are very close to criteria, or that may be associated with insignificant quantities of hazardous substances.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR **GROUNDWATER** DATA	Statistical Guidesheet 2
GENERIC COMMERCIAL II, III, IV AND INDUSTRIAL DRINKING WATER CRITERIA (DWC)	
May assist in evaluation of condition(s):	2
Applicability of Statistics	**NO**
Statistics are not applicable for assessing this exposure pathway because the point of exposure is presumed to be any point in the affected aquifer. As a result, cleanup criteria must be met at all points.	

Key Considerations:		
	Section 1	**Facility Determination**
		• Not applicable.
	Section 2	**Selection of Data For Statistical Analysis**
		• Not applicable – see Section 3.
	Section 3	**Risk Analysis – Comparison to Criteria**
		★ Statistical analysis of *FACILITY* groundwater concentrations for comparison to criteria (either across well locations or over time in an individual well) is not acceptable. Since the point of exposure is presumed to be any point in the affected aquifer, groundwater drinking water criteria must be met at each point in an aquifer. Therefore, evaluation of groundwater concentrations must be completed on a point-by-point basis* (i.e., each concentration at a given time and location must be compared individually to criteria). • If *BACKGROUND* concentrations are greater than criteria for naturally occurring substances, groundwater concentrations may be compared to *BACKGROUND* concentrations. If comparison is made to *BACKGROUND* the comparison must be completed on a point-by-point basis.* See Statistical Guidesheet 10 and Chapter 4 of the tabbed section titled, "Statistical Methods." ★ Statistical analysis of groundwater concentrations over time in an individual well will not be allowed for comparison to criteria or *BACKGROUND*.
	Section 4	**Verification of Remediation or Closure**
		• **No Action Needed**: If the data evaluation completed under Section 3 demonstrates that there are no exceedances of cleanup criteria, no remedial action is required for this pathway and consequently no additional sampling or data analysis is required under Section 4.

	Section 4: (Continued)	• **In situ/Ex situ Treatment**: Plans for verifying remediation or closure must be made on a case-by-case basis and must demonstrate how treatment is effective in meeting cleanup criteria. To demonstrate verification of remediation or closure, concentrations in groundwater must meet criteria during a specified number of consecutive sampling events. The number of consecutive sampling events must be selected on a case-by-case basis to reflect seasonal variation in groundwater quality, flow rates, and initial distribution of contamination in groundwater. Ordinarily, this demonstration should be made using data from at least one year of quarterly sampling. • **Containment**: Generally groundwater sampling used to verify a groundwater containment remedy will be done at the perimeter of the containment system. Statistical analysis is not allowed for reasons described in Section 3. This verification will be an ongoing part of the remedy as long as hazardous substances are present above criteria. • Comparisons to criteria or *BACKGROUND* must be made on a point-by-point basis.* See Section 3.
Additional Information:		Criteria Application Guidesheet 2
Recommended Statistical Methods for Comparison to Criteria:		Not applicable.

*Professional judgment is required to interpret the significance of exceedances that are very close to criteria, or that may be associated with insignificant quantities of hazardous substances.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR **GROUNDWATER** DATA	Statistical Guidesheet 3
GENERIC AND MIXING ZONE-BASED GROUNDWATER SURFACE WATER INTERFACE (GSI) CRITERIA	
May assist in evaluation of condition(s):	5
Applicability of Statistics	**YES - Chronic; NO - Generic and Acute**

Statistics are applicable for evaluating compliance with chronic mixing zone-based GSI criteria since the "average" impact of hazardous substances in groundwater is considered. Statistics are not applicable for acute mixing zone-based GSI criteria, since point-by-point exceedances of these criteria can result in unacceptable impacts. Statistics are also not applicable for comparison to generic GSI criteria, since these criteria do not take into account any dilution or mixing with receiving waters.

Key Considerations:

Section 1

Facility Determination

- For the purposes of a BEA or initial *FACILITY* determination, property may be classified as a *FACILITY* if one or more samples contain concentrations above generic residential criteria or *BACKGROUND* concentrations, whichever is greater, provided that there is not a greater body of evidence that the property is not a *FACILITY*. For purposes other than *FACILITY* determination (e.g., remediation and/or closure), additional data will likely be required.
- If a statistical analysis is relied upon for making a *FACILITY* determination see Sections 2 and 3.

★ In certain cases, professional judgment may dictate that this pathway is not relevant due to lack of proximity to the surface water and other factors described in Cleanup Criteria Application Guidesheet 3. In this case, these criteria are not applicable and are not the basis for a property being considered a *FACILITY*.

Section 2

Selection of Data For Statistical Analysis

★ Samples collected for the purpose of characterizing a *FACILITY* are typically biased, based on factors such as historical information, previous sampling, disposal practices, visual impacts, and aerial photos. Once the nature and extent of contamination has been defined, it is necessary to identify and/or obtain data that will allow for appropriate comparison to criteria. There are two primary considerations in determining if data sets are adequate. First, data sets must be obtained from appropriately placed wells at the GSI. Second, if statistics are used, data sets must be from the *AVERAGING AREA* and contain a sufficient number of sample results to allow for proper statistical analysis and development of *REPRESENTATIVE CONCENTRATIONS*. Therefore, additional sampling to develop *REPRESENTATIVE CONCENTRATIONS* is often required after the nature and extent of contamination have been defined.

★ A statistical analysis is appropriate only if the nature and extent of contamination, including any *HOT SPOTS*, has been adequately defined. This means that the horizontal and vertical extent of contamination exceeding generic GSI criteria in groundwater, and sources that may result in GSI criteria exceedances in the future, must be defined.

Section 2: (Continued)

The following bullets relate to evaluation of groundwater data from *GSI MONITORING WELLS* only:

★ Statistical analysis of groundwater data is not allowed for comparison to generic GSI criteria or acute mixing zone-based criteria.

★ Statistical analysis of groundwater data from *GSI MONITORING WELLS* is allowed for comparison to chronic mixing zone-based criteria only. Only groundwater data from *GSI MONITORING WELLS* within the *AVERAGING AREA* may be used for statistical comparison to chronic mixing zone-based GSI criteria. The *AVERAGING AREA* is the cross sectional area of the hazardous substance plume used to estimate the discharge rate of venting groundwater in the request for a mixing zone determination. This cross section represents the area in which hazardous substance concentrations exceed or are expected to exceed the generic GSI criteria.

★ It is appropriate to combine samples from *HOT SPOT* areas within the *AVERAGING AREA* with samples from other areas within the *AVERAGING AREA* for statistical purposes when comparing data to chronic mixing zone based criteria.

★ The horizontal limits of the cross sectional area typically extend to the nearest adjacent wells along the GSI in which groundwater concentrations are consistently below generic GSI criteria; it is assumed that groundwater concentrations exceed generic GSI criteria up to these boundary points. Therefore, the horizontal boundaries of the cross sectional area extend up to, but do not include, these adjacent wells. Consequently, the adjacent wells (below generic GSI) should not be included in the *AVERAGING AREA* and data from these wells should not be included in the statistical analysis.

★ Different *AVERAGING AREAS* may be required for different hazardous substances depending on whether more than one cross sectional area was used to estimate discharge rates of venting groundwater in the request for the mixing zone determination.

★ The groundwater data used in the statistical analysis must be representative of the *AVERAGING AREA* and include all monitoring points located within the *AVERAGING AREA*. Samples from a minimum of nine distinct GSI monitoring points must be used in the statistical analysis. This does not necessarily mean nine individual wells (e.g., three screened intervals in each of two wells would yield nine distinct monitoring points). This number is based on statistical considerations only, but may not be practical for groundwater plumes that have very narrow *AVERAGING AREAS*. Additional samples may be necessary to represent spatial variability in the *AVERAGING AREA* depending on such factors as soil type, and size of the *AVERAGING AREA*.

★ Statistical analysis of groundwater data over time is not allowed for comparison to chronic mixing zone-based criteria. The statistical analysis must generally be completed using data from a single sampling event. If resampling is conducted to confirm the presence of elevated hazardous substance concentrations in one or more individual wells, results from resampling should not be incorporated into the statistical analysis. However, all wells in the *AVERAGING AREA* may be resampled for the purpose of a separate statistical evaluation.

Section 3

Risk Analysis – Comparison to Criteria

★ In certain cases, professional judgment may dictate that these criteria are not applicable due to lack of proximity to surface water and other factors as described in Cleanup Criteria Application Guidesheet 3.

	Section 3: (Continued)	★ Comparison of groundwater data to generic GSI criteria and acute mixing zone-based criteria must be completed on a point-by-point basis.* That is, statistical analysis of groundwater concentrations across well locations or over time in an individual well will not be allowed for comparison to these criteria. ★ Whole effluent acute toxicity test results must be compared to the *ONE ACUTE TOXIC UNIT* criterion on a point-by-point basis.* The *ONE ACUTE TOXIC UNIT* has the same regulatory significance as an acute mixing-zone-based GSI criterion. ★ Statistical analysis of groundwater data is allowed for comparison to chronic mixing zone-based criteria only. Only data from *GSI MONITORING WELLS* within the *AVERAGING AREA* may be included in the statistical analysis. The statistical analysis must generally be completed using data from a single sampling event. See Section 2 for a description of the *AVERAGING AREA* and additional details on *FACILITY* characterization data that may be included in the statistical analysis. • Statistical analyses must include an evaluation of the underlying statistical distribution of the data (i.e., normal, lognormal, or neither) and the level of censoring (i.e., proportion of the data below the detection limit). See the tabbed section titled, "Statistical Methods." This evaluation must be completed for each hazardous substance. The statistical method used for comparison of groundwater data to chronic mixing zone-based criteria must be selected for each hazardous substance based on statistical distribution and level of censoring. ★ If *BACKGROUND* concentrations are greater than criteria for naturally occurring substances, groundwater data may be compared to *BACKGROUND* concentrations. This evaluation will generally be made on a point-by-point basis,* except for certain chronic mixing zone-based criteria. See Statistical Guidesheet 10 and Chapter 4 of the tabbed section titled, "Statistical Methods."
	Section 4	**Verification of Remediation or Closure** • For the purposes of verification of remediation or closure, compliance of groundwater data with GSI criteria at the GSI may be determined in the same manner described in Section 3. To demonstrate verification of remediation or closure, concentrations in groundwater must meet criteria during a specified number of consecutive sampling events. The number of consecutive sampling events must be selected on a case-by-case basis to reflect seasonal variation in groundwater quality, flow rates, and initial distribution of contamination in groundwater. ★ **No Action Needed**: If the data evaluation completed under Sections 2 and 3 demonstrated that there are no exceedances of generic GSI criteria, and there is no reason to believe there will be exceedances in the future at the GSI, no remedial action is required for this pathway and consequently no additional sampling or data analysis is required under Section 4. • **In situ/Ex situ Treatment**: For the purposes of verification of remediation or closure, compliance of groundwater data with these criteria may be determined in the same manner described in Section 3. Plans for verifying remediation or closure must be made on a case-by-case basis and must demonstrate how treatment is effective in meeting cleanup criteria. These plans may or may not depend on statistical analysis of data as allowed in Sections 2 and 3. To demonstrate verification of remediation or closure, concentrations in groundwater must meet criteria during a specified number of consecutive sampling events. The number of consecutive sampling events must be selected on a case-by-case basis to reflect seasonal variation in groundwater quality, flow rates, and initial distribution of contamination in groundwater.

	Section 4: (Continued)	• **Containment**: For the purposes of verification of remediation or closure, compliance of groundwater data with these criteria may be determined in the same manner described in Section 3. Generally groundwater sampling used to verify a groundwater containment remedy will be done at the perimeter of the containment system. These plans may or may not depend on statistical analysis of data as allowed in Sections 2 and 3. This verification will be ongoing part of the remedy as long as hazardous substances are present above criteria. ★ **For all the preceding cases**, in addition to demonstrating compliance with GSI criteria at the GSI, it is necessary to demonstrate that groundwater at the GSI will continue to meet GSI criteria for verification of remediation or closure. This demonstration must include an evaluation of upgradient groundwater and soil concentrations and sources. ★ If *BACKGROUND* concentrations are greater than criteria for naturally occurring substances, groundwater data may be compared to *BACKGROUND* concentrations. This evaluation will generally be made on a point-by-point basis,* except for certain chronic mixing zone-based criteria. See Statistical Guidesheet 10 and Chapter 4 of the tabbed section titled, "Statistical Methods."
Additional Information:		Criteria Application Guidesheet 3
Recommended Statistical Methods for Comparison to Criteria:		For chronic mixing zone-based criteria only, compare *FACILITY* data to criteria using a 95% upper confidence limit (UCL) for the mean concentration (see Chapter 3 of the tabbed section titled, "Statistical Methods"). Other statistical methods may be acceptable on a case-by-case basis.

*Professional judgment is required to interpret the significance of exceedances that are very close to criteria, or that may be associated with insignificant quantities of hazardous substances.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR GROUNDWATER DATA	**Statistical Guidesheet 4**

GENERIC RESIDENTIAL AND COMMERCIAL I GROUNDWATER VOLATILIZATION TO INDOOR AIR INHALATION CRITERIA (GVIIC)

May assist in evaluation of condition(s):	4
Applicability of Statistics	**GNP**

Statistics are generally not practical as a tool for assessing this exposure pathway because of the spatial and temporal variability of groundwater hazardous substance plumes and the resulting soil gas plumes that are generated from hazardous substances in groundwater.

Key Considerations:

Section 1

Facility Determination

- For the purposes of a BEA or initial *FACILITY* determination, property may be classified as a *FACILITY* if one or more samples contain concentrations above generic residential criteria, provided that there is not a greater body of evidence that the property is not a *FACILITY*. For purposes other than *FACILITY* determination (e.g., remediation and/or closure), additional data will likely be required.
- If a statistical analysis is relied upon for making a *FACILITY* determination see Sections 2 and 3.

Section 2

Selection of Data For Statistical Analysis

- Samples collected for the purpose of characterizing a *FACILITY* are typically biased, based on factors such as historical information, previous sampling, disposal practices, visual impacts, and aerial photos. Once the nature and extent of contamination has been defined, it is necessary to identify and/or obtain data that will allow for appropriate comparison to criteria. There are two primary considerations in determining if data sets are adequate. First, data sets must be obtained from locations that are consistent with the exposure assumptions for the relevant land use scenario. Second, if statistics are used, data sets must contain a sufficient number of *RANDOMLY* located sample results to allow for proper statistical analysis and development of *REPRESENTATIVE CONCENTRATIONS*. Therefore, additional sampling to develop *REPRESENTATIVE CONCENTRATIONS* will often be required after the nature and extent of contamination have been defined. Some characterization data may be used in the development of a *REPRESENTATIVE CONCENTRATION* as described in Section 2.4.2 of the tabbed section titled, "Sampling Strategies."
- A statistical analysis is appropriate only if the nature and extent of contamination, including any *HOT SPOTS*, has been adequately defined.
- It is not appropriate to combine samples from *HOT SPOT* areas with samples from other areas of a property for statistical analysis. This is necessary to avoid averaging or diluting the samples that represent *HOT SPOTS*. *HOT SPOTS* must be addressed separately. See Section 2.2.1.1 of the tabbed section titled "Sampling Strategies."
- ★ Sample locations with concentrations equal to or greater than the hazardous substance's water solubility must not be included in the data set for statistical evaluation. Areas where data exceed solubility must be addressed separately and cannot be ignored.

	Section 2 (Continued)	★ Generally only groundwater data from a 1,200 ft^2 *EXPOSURE UNIT* (i.e., the building footprint) may be used in a statistical calculation for remedial compliance.
	Section 3	**Risk Analysis – Comparison to Criteria** ★ Statistical analysis of *FACILITY* groundwater data for comparison to GVIIC is generally not practical given the spatial and temporal variability of groundwater plumes and the dynamics of the resulting soil gas plume that is generated by hazardous substances in groundwater. Determining the impact of these factors within a 1,200 ft^2 area (i.e., the building footprint) further complicates application of statistical approaches. As a result, comparison to these criteria will generally be completed on a point-by-point basis* (i.e., each concentration at each location must be compared individually to criteria). • If DEQ approval of a response activity is being sought, a *PROPOSAL* for a statistical analysis must be submitted to the DEQ for approval to assure that data needs and/or complexities of the pathway are addressed. • Statistical analysis of groundwater concentrations over time in an individual well will not be allowed for comparison to criteria.
	Section 4	**Verification of Remediation or Closure** • **No Action Needed**: If the data evaluation completed under Sections 2 and 3 demonstrated that there are no exceedances of cleanup criteria, no remedial action is required for this pathway and consequently no additional sampling or data analysis is required under Section 4. • **In situ/Ex situ Treatment**: Plans for verifying remediation or closure must be made on a case-by-case basis and must demonstrate how treatment is effective in meeting cleanup criteria. To demonstrate verification of remediation or closure, concentrations in groundwater must meet criteria during a specified number of consecutive sampling events. The number of consecutive sampling events must be selected on a case-by-case basis to reflect seasonal variation in groundwater quality, flow rates, and initial distribution of contamination in groundwater. Ordinarily, this demonstration should be made using data from at least one year of quarterly sampling. • **Cover/Containment**: In the context of this pathway, cover/containment will typically be a vapor barrier. Generally groundwater sampling will not be used to verify remediation or closure that relies on vapor barrier. Verification of remediation in areas outside the cover/containment structure will be done using the options above. • Statistical analysis of groundwater concentrations over time in an individual well will not be allowed for comparison to criteria.

Additional Information	Criteria Application Guidesheet 4
Recommended Statistical Methods for Comparison to Criteria:	If statistical analysis is documented to be practical, the recommended statistical method is comparison of *FACILITY* data to criteria using a 95% upper confidence limit (UCL) for the mean concentration (see Chapter 3 of the tabbed section titled, "Statistical Methods"). Other statistical methods may be acceptable on a case-by-case basis.

*Professional judgment is required to interpret the significance of exceedances that are very close to criteria, or that may be associated with insignificant quantities of hazardous substances.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR **GROUNDWATER** DATA	Statistical Guidesheet 5

GENERIC COMMERCIAL II, III, IV AND INDUSTRIAL GROUNDWATER VOLATILIZATION TO INDOOR AIR INHALATION CRITERIA (GVIIC)

May assist in evaluation of condition(s):	4
Applicability of Statistics	**GNP**

Statistics are generally not practical as a tool for assessing this exposure pathway because of the spatial and temporal variability of groundwater hazardous substance plumes and the resulting soil gas plumes that are generated from hazardous substances in groundwater.

Key Considerations:

Section 1

Facility Determination

- Not applicable.

Section 2

Selection of Data For Statistical Analysis

- Samples collected for the purpose of characterizing a *FACILITY* are typically biased, based on factors such as historical information, previous sampling, disposal practices, visual impacts, and aerial photos. Once the nature and extent of contamination has been defined, it is necessary to identify and/or obtain data that will allow for appropriate comparison to criteria. There are two primary considerations in determining if data sets are adequate. First, data sets must be obtained from locations that are consistent with the exposure assumptions for the relevant land use scenario. Second, if statistics are used, data sets must contain a sufficient number of *RANDOMLY* located sample results to allow for proper statistical analysis and development of *REPRESENTATIVE CONCENTRATIONS*. Therefore, additional sampling to develop *REPRESENTATIVE CONCENTRATIONS* will often be required after the nature and extent of contamination have been defined. Some characterization data may be used in the development of a *REPRESENTATIVE CONCENTRATION* as described in Section 2.4.2 of the tabbed section titled, "Sampling Strategies."

- A statistical analysis is appropriate only if the nature and extent of contamination, including any *HOT SPOTS*, has been adequately defined.

- It is not appropriate to combine samples from *HOT SPOT* areas with samples from other areas of a property for statistical analysis. This is necessary to avoid averaging or diluting the samples that represent *HOT SPOTS*. *HOT SPOTS* must be addressed separately. See Section 2.2.1.1 of the tabbed section titled, "Sampling Strategies."

★ Sample locations with concentrations equal to or greater than the hazardous substance's water solubility must not be included in the data set for statistical evaluation. Areas where data exceed solubility must be addressed separately and cannot be ignored.

★ Generally only groundwater data from a 4,000 ft^2 *EXPOSURE UNIT* (i.e., the building footprint) may be used in a statistical calculation for remedial compliance.

	Section 3	**Risk Analysis – Comparison to Criteria**
		★ Statistical analysis of *FACILITY* groundwater concentrations for comparison to GVIIC is generally not practical given the spatial and temporal variability of groundwater plumes and the dynamics of the resulting soil gas plume that is generated by hazardous substances in groundwater. Determining the impact of these factors within a 4,000 ft^2 area (i.e., the building footprint) adds further complications with application of statistical approaches. As a result, comparison to these criteria will generally be completed on a point-by-point basis* (i.e., each concentration at each location must be compared individually to criteria). • If DEQ approval of a response activity is being sought, a *PROPOSAL* for a statistical analysis must be submitted to the DEQ for approval to assure that data needs and/or complexities of the pathway are addressed. • Statistical analysis of groundwater concentrations over time in an individual well will not be allowed for comparison to criteria.
	Section 4	**Verification of Remediation or Closure**
		• **No Action Needed**: If the data evaluation completed under Sections 2 and 3 demonstrated that there are no exceedances of cleanup criteria, no remedial action is required for this pathway and consequently no additional sampling or data analysis is required under Section 4. • **In situ/Ex situ Treatment**: Plans for verifying remediation or closure must be made on a case-by-case basis and must demonstrate how treatment is effective in meeting cleanup criteria. To demonstrate verification of remediation or closure, concentrations in groundwater must meet criteria during a specified number of consecutive sampling events. The number of consecutive sampling events must be selected on a case-by-case basis to reflect seasonal variation in groundwater quality, flow rates, and initial distribution of contamination in groundwater. Ordinarily, this demonstration should be made using data from at least one year of quarterly sampling. • **Cover/Containment**: In the context of this pathway, cover/containment will typically be a vapor barrier. Generally groundwater sampling will not be used to verify remediation or closure that relies on a vapor barrier. Verification of remediation in areas outside the cover/containment structure will be done using the options above. • Statistical analysis of groundwater concentrations over time in an individual well will not be allowed for comparison to criteria.

Additional Information:	Criteria Application Guidesheet 5
Recommended Statistical Methods for Comparison to Criteria:	If statistical analysis is documented to be practical, the recommended statistical method is comparison of *FACILITY* data to criteria using a 95% upper confidence limit (UCL) for the mean concentration (see Chapter 3 of the tabbed section titled, "Statistical Methods"). Other statistical methods may be acceptable on a case-by-case basis.

*Professional judgment is required to interpret the significance of exceedances that are very close to criteria, or that may be associated with insignificant quantities of hazardous substances.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR **GROUNDWATER** DATA	Statistical Guidesheet 6
GENERIC GROUNDWATER CONTACT CRITERIA (GCC)	
May assist in evaluation of condition(s):	3
Applicability of Statistics	**GNP**

Statistics are generally not practical as a tool for assessing this exposure pathway because it is unlikely that a sufficient number of samples will be collected to allow for valid analysis in the very small areas where groundwater contact may occur.

Key Considerations:

Section 1

Facility Determination

- For the purposes of a BEA or initial *FACILITY* determination, property may be classified as a *FACILITY* if one or more samples contain concentrations above generic residential criteria or *BACKGROUND* concentrations, whichever is greater, provided that there is not a greater body of evidence that the property is not a *FACILITY*. For purposes other than *FACILITY* determination (e.g., remediation and/or closure), additional data will likely be required.
- If a statistical analysis is relied upon for making a *FACILITY* determination see Sections 2 and 3.
- ★ In certain cases, professional judgment may dictate that this pathway is not relevant if the depth to groundwater is greater than the depth to utilities and the depth at which other subsurface work may be performed. These factors and additional considerations are described in Criteria Application Guidesheet 6. If the pathway is not relevant, these criteria are not applicable and are not the basis for a property being considered a *FACILITY*.

Section 2

Selection of Data For Statistical Analysis

- Samples collected for the purpose of characterizing a *FACILITY* are typically biased, based on factors such as historical information, previous sampling, disposal practices, visual impacts, and aerial photos. Once the nature and extent of contamination has been defined, it is necessary to identify and/or obtain data that will allow for appropriate comparison to criteria. There are two primary considerations in determining if data sets are adequate. First, data sets must be obtained from locations that are consistent with the exposure assumptions for the relevant land use scenario. Second, if statistics are used, data sets must contain a sufficient number of *RANDOMLY* located sample results to allow for proper statistical analysis and development of *REPRESENTATIVE CONCENTRATIONS*. Therefore, additional sampling to develop *REPRESENTATIVE CONCENTRATIONS* will often be required after the nature and extent of contamination have been defined. Some characterization data may be used in the development of a *REPRESENTATIVE CONCENTRATION* as described in Section 2.4.2 of the tabbed section titled, "Sampling Strategies."
- A statistical analysis is appropriate only if the nature and extent of contamination, including any *HOT SPOTS*, has been adequately defined.
- It is not appropriate to combine samples from *HOT SPOT* areas with samples from other areas of a property for statistical analysis. This is necessary to avoid averaging or diluting the samples that represent *HOT SPOTS. HOT SPOTS* must be addressed separately. See Section 2.2.1.1 of the tabbed section titled, "Sampling Strategies."

	Section 3	**Risk Analysis – Comparison to Criteria**
		★ In certain cases, professional judgment may dictate that these criteria are not applicable due to factors such as depth to groundwater relative to the depth where subsurface activities may occur, and other factors as described in Criteria Application Guidesheet 6. ★ Statistical analysis of *FACILITY* groundwater concentrations for comparison to criteria is generally not practical, since exposure to groundwater may be limited to very small areas such as an area the size of a manhole. Therefore, comparisons to GCC will generally be completed on a point-by-point basis* (i.e., each concentration at each time and location must be compared individually to criteria). • If DEQ approval of a response activity is being sought, a *PROPOSAL* for a statistical analysis must be submitted to the DEQ for approval to assure that data needs and/or complexities of the pathway are addressed. • If *BACKGROUND* concentrations are greater than criteria for naturally occurring substances, groundwater concentrations may be compared to *BACKGROUND* concentrations. See Statistical Guidesheet 10 and Chapter 4 of the tabbed section titled, "Statistical Methods." This evaluation will generally be made on a point-by-point basis* because of the lack of data. • Statistical analysis of groundwater concentrations over time in an individual well will not be allowed for comparison to criteria or *BACKGROUND*.
	Section 4	**Verification of Remediation or Closure**
		• **No Action Needed**: If the data evaluation completed under Sections 2 and 3 demonstrated that there are no exceedances of cleanup criteria, no remedial action is required for this pathway and consequently no additional sampling or data analysis is required under Section 4. • **In situ/Ex situ Treatment**: For the purposes of verification of remediation or closure, compliance of groundwater data with these criteria may be determined in the same manner described in Section 3. Plans for verifying remediation or closure must be made on a case-by-case basis and must demonstrate how treatment is effective in meeting cleanup criteria. These plans may or may not depend on statistical analysis of data as allowed in Sections 2 and 3. To demonstrate verification of remediation or closure, concentrations in groundwater must meet criteria during a specified number of consecutive sampling events. The number of consecutive sampling events must be selected on a case-by-case basis to reflect seasonal variation in groundwater quality, flow rates, and initial distribution of contamination in groundwater. Ordinarily, this demonstration should be made using data from at least one year of quarterly sampling. • **Containment**: Generally groundwater sampling used to verify a groundwater containment remedy will be done at the perimeter of the containment system. Statistical analysis is generally not practical for reasons described in Sections 2 and 3. This verification will be an ongoing part of the remedy as long as hazardous substances are present above criteria. • If *BACKGROUND* concentrations are greater than criteria for naturally occurring substances, groundwater concentrations may be compared to *BACKGROUND* concentrations. See Statistical Guidesheet 10 and Chapter 4 of the tabbed section titled, "Statistical Methods." This evaluation will generally be made on a point-by-point basis* because of the lack of data.

Additional Information:	Criteria Application Guidesheet 6
Recommended Statistical Methods for Comparison to Criteria:	If statistical analysis is documented to be practical, the recommended statistical method is comparison of *FACILITY* data to criteria using a 95% upper confidence limit (UCL) for the mean concentration (see Chapter 3 of the tabbed section titled, "Statistical Methods"). Other statistical methods may be acceptable on a case-by-case basis.

*Professional judgment is required to interpret the significance of exceedances that are very close to criteria, or that may be associated with insignificant quantities of hazardous substances.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR **GROUNDWATER** DATA	Statistical Guidesheet 7
WATER SOLUBILITY	
May assist in evaluation of condition(s):	1-5
Applicability of Statistics	**Pathway Dependent**
See the Statistical Guidesheet for the exposure pathway where the cleanup criterion defaults to water solubility to determine the applicability of statistics.	

Key Considerations:	**Section 1**	**Facility Determination**
		• See the Statistical Guidesheet for the generic criterion that defaults to the water solubility value.
	Section 2	**Selection of Data For Statistical Analysis**
		• See the Statistical Guidesheet for the generic criterion that defaults to the water solubility value. • Data that are greater than water solubility should not be included in a statistical analysis.
	Section 3	**Risk Analysis – Comparison to Criteria**
		• See Section 2.
	Section 4	**Verification of Remediation or Closure**
		• See Section 2.

Additional Information:	Criteria Application Guidesheets 7 and A, and Appendix A.
Recommended Statistical Methods for Comparison to Criteria:	See Statistical Guidesheets for relevant exposure pathways.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR **GROUNDWATER** DATA	Statistical Guidesheet 8

GENERIC SCREENING LEVELS FOR FLAMMABILITY AND EXPLOSIVITY

May assist in evaluation of condition(s):	3, 4, 14
Applicability of Statistics	**GNP**

Statistics are generally not practical as a tool for assessing this condition because it deals with acute risks and any exceedance of screening levels requires further consideration.

Key Considerations:

Section 1

Facility Determination

- The determination that property is a *FACILITY* is generally based on data which show that one or more generic residential cleanup criterion is exceeded. Since the values developed for this condition are screening levels and not cleanup criteria, *FACILITY* determinations generally will not be based on this condition. If you are evaluating property where you suspect problems with this condition and no data are available to demonstrate that the property is a *FACILITY* for other reasons, consult your supervisor for guidance.

Section 2

Selection of Data For Statistical Analysis

- Not applicable - see Section 3.

Section 3

Risk Analysis – Comparison to Criteria

★ Since this condition deals with acute risks, any exceedance of screening levels requires further consideration. Statistical treatment of data is not expected to be a practical tool for making decisions about the need for response activity related to this condition. Professional judgment will be required to determine the significance of any data that relates to this condition. The quantity of the hazardous substance that is present above its screening level(s) is a factor that determines whether there may be an unacceptable risk.

Section 4

Verification of Remediation or Closure

- See Section 3.

Additional Information:	Criteria Application Guidesheet 8
Recommended Statistical Methods for Comparison to Criteria:	The statistical method for comparing *FACILITY* data to criteria will be determined on a case-by-case basis.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR **GROUNDWATER** DATA	Statistical Guidesheet 9

GENERIC ACUTE INHALATION TOXICITY SCREENING LEVELS

May assist in evaluation of condition(s):	3, 4, 14

Applicability of Statistics	GNP

Statistics are generally not practical as a tool for assessing this condition because it deals with acute risks and any exceedance of screening levels requires further consideration.

Key Considerations:

Section 1

Facility Determination

- The determination that property is a *FACILITY* is generally based on data which show that one or more generic residential cleanup criterion is exceeded. Since the values developed for this condition are screening levels and not cleanup criteria, *FACILITY* determinations generally will not be based on this condition. If you are evaluating property where you suspect problems with this condition and no data are available to demonstrate that the property is a *FACILITY* for other reasons, consult your supervisor for guidance.

Section 2

Selection of Data For Statistical Analysis

- Not applicable - see Section 3.

Section 3

Risk Analysis – Comparison to Criteria

★ Since this condition deals with acute risks, any exceedance of screening levels requires further consideration. Statistical treatment of data is not expected to be a practical tool for making decisions about the need for response activity related to this condition. Professional judgment will be required to determine the significance of any data that relates to this condition. The quantity of the hazardous substance that is present above its screening level(s) is a factor that determines whether there may be an unacceptable risk.

Section 4

Verification of Remediation or Closure

- See Section 3.

Additional Information:	Criteria Application Guidesheet 9
Recommended Statistical Methods for Comparison to Criteria:	The statistical method for comparing *FACILITY* data to criteria will be determined on a case-by-case basis.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR SOIL DATA	**Statistical Guidesheet 10**
SOIL BACKGROUND	
May assist in evaluation of Condition(s):	6-12
Applicability of Statistics	**YES - Determining *BACKGROUND*; Pathway Dependent - Comparison to *FACILITY* Data**

See the Statistical Guidesheet for the soil exposure pathway to determine if criteria may default to *BACKGROUND* and if statistical analysis of *FACILITY* data is appropriate for comparison to *BACKGROUND* (or if a point-by-point comparison of *FACILITY* data to *BACKGROUND* is necessary).

Key Considerations:	**Section 1**	**Facility Determination**
		• For the purposes of a BEA or initial *FACILITY* determination, property may be classified as a *FACILITY* if one or more samples contain concentrations above generic residential criteria or *BACKGROUND* concentrations, whichever is greater, provided that there is not a greater body of evidence that the property is not a *FACILITY*. However, if concentrations of a hazardous substance from the property are less than the *STATEWIDE DEFAULT BACKGROUND* concentration in Operational Memorandum #15 for that hazardous substance, the property is not a *FACILITY* with respect to that hazardous substance. For purposes other than *FACILITY* determination (e.g., remediation and/or closure), additional data will likely be required. • If a statistical analysis is relied upon for making a *FACILITY* determination see Sections 2 and 3.
	Section 2	**Selection of Data For Statistical Analysis**
		★ For all other Statistical Guidesheets, this section addresses selection of *FACILITY* data for statistical analysis. However, for this Statistical Guidesheet, the following comments address selection of *BACKGROUND* data for establishing *BACKGROUND* concentrations. ★ Establishing soil *BACKGROUND* can be accomplished by utilizing the *STATEWIDE DEFAULT BACKGROUND* criteria provided in Operational Memorandum #15 or by developing *FACILITY-SPECIFIC BACKGROUND* criteria. In addition, *REGIONAL BACKGROUND* may be *PROPOSED* on a case-by-case basis, as described in Operational Memorandum #15. ★ If multiple soil horizons are present at a *FACILITY*, *FACILITY-SPECIFIC BACKGROUND* should be established for each distinct soil horizon being evaluated at the *FACILITY*. ★ *FACILITY-SPECIFIC BACKGROUND* samples should be taken in each distinct soil type or horizon and at comparable depths to *FACILITY* soil samples being compared to *FACILITY-SPECIFIC BACKGROUND*. A minimum of nine samples for each distinct soil horizon should be used to establish *FACILITY-SPECIFIC BACKGROUND* concentrations. This is to help account for the natural variability inherent within each distinct soil horizon. Fewer than nine samples may be *PROPOSED* on a case-by-case basis.

<table>
<tr><td rowspan="3"></td><td>Section 2: (Continued)</td><td>★ FACILITY-SPECIFIC BACKGROUND samples must reflect naturally occurring concentrations except as described in the following bullet. This is necessary to comply with the definition of BACKGROUND under Part 201:

“The concentration or level of a hazardous substance which exists in the environment at or regionally proximate to a site that is not attributable to any release at or regionally proximate to the site.”

★ BACKGROUND soil samples are typically used to establish naturally occurring levels of metals. NON-RELEASE ANTHROPOGENIC BACKGROUND may be PROPOSED on a case-by-case basis for other classes of hazardous substances if the presence of these hazardous substances is not present due to a RELEASE (e.g., compounds present in the soil resulting from application of pesticides in accordance with label directions).

★ FACILITY-SPECIFIC BACKGROUND samples should be collected using the same methodology, analytical methods and detection limits as FACILITY samples.

★ BACKGROUND soil samples must be analyzed using methods and detection limits found in Operational Memorandum #6, Rev 5.</td></tr>
<tr><td rowspan="2">Section 3</td><td>Risk Analysis – Comparison to Criteria</td></tr>
<tr><td>★ According to Section 20a(11), BACKGROUND concentrations become the Part 201 cleanup criteria when BACKGROUND concentrations are greater than corresponding risk-based criteria.

★ The recommended statistical method for comparing FACILITY data to BACKGROUND depends on the type of BACKGROUND being used and whether a statistical analysis was appropriate for comparing FACILITY data to Part 201 risk-based criteria. See Chapter 4 of the tabbed section titled, “Statistical Methods.”

• When FACILITY-SPECIFIC BACKGROUND is utilized, the analysis OF FACILITY-SPECIFIC BACKGROUND data must include an evaluation of the underlying statistical distribution of the data (i.e., normal, lognormal, or neither) and level of censoring (i.e., proportion of data below the detection limit). See the tabbed section titled, “Statistical Methods.” This evaluation must be completed for each hazardous substance.

• The presence of outliers in the FACILITY-SPECIFIC BACKGROUND data set should be evaluated using the procedures outlined in Chapter 2 of the tabbed section titled, “Statistical Methods.”</td></tr>
<tr><td rowspan="2">Section 4</td><td>Verification of Remediation or Closure</td></tr>
<tr><td>★ Refer to the statistical guidesheets corresponding to the pathway/condition. When appropriate, verification samples may be compared to BACKGROUND concentrations as described in Sections 2 and 3 of this guidesheet.</td></tr>
<tr><td colspan="2">Additional Information:</td><td>Criteria Application Guidesheet 10</td></tr>
<tr><td colspan="2">Recommended Statistical Methods for Comparison to Criteria:</td><td>See Chapter 4 of the tabbed section titled, “Statistical Methods.” Other statistical methods may be acceptable on a case-by-case basis.</td></tr>
</table>

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR SOIL DATA	**Statistical Guidesheet 11**
GENERIC SOIL CRITERIA PROTECTIVE OF RESIDENTIAL AND COMMERCIAL I DRINKING WATER	
May assist in evaluation of condition(s):	9
Applicability of Statistics	**GNP**
Statistics are generally not practical as a tool for assessing this exposure pathway because of the difficulty in projecting the impact on groundwater of hazardous substances in soil and the need to assure that drinking water cleanup criteria are met at all points in the aquifer.	

Key Considerations:		
	Section 1	**Facility Determination** • For the purposes of a BEA or initial *FACILITY* determination, property may be classified as a *FACILITY* if one or more samples contain concentrations above generic residential criteria or *BACKGROUND* concentrations, whichever is greater, provided that there is not a greater body of evidence that the property is not a *FACILITY* or leachate sample results are less than the groundwater criterion. However, if concentrations of a hazardous substance from the property are less than the *STATEWIDE DEFAULT BACKGROUND* value in Operational Memorandum #15 for that hazardous substance, the property is not a *FACILITY* with respect to that hazardous substance. For purposes other than *FACILITY* determination (e.g., remediation and/or closure), additional data will likely be required. • If a statistical analysis is relied upon for making a *FACILITY* determination see Sections 2 and 3.
	Section 2	**Selection of Data For Statistical Analysis** • Samples collected for the purpose of characterizing a *FACILITY* are typically biased, based on factors such as historical information, previous sampling, disposal practices, visual impacts, and aerial photos. Once the nature and extent of contamination has been defined, it is necessary to identify and/or obtain data that will allow for appropriate comparison to criteria. There are two primary considerations in determining if data sets are adequate. First, data sets must be obtained from locations that are consistent with the exposure assumptions for the relevant land use scenario. Second, if statistics are used, data sets must contain a sufficient number of *RANDOMLY* located sample results to allow for proper statistical analysis and development of *REPRESENTATIVE CONCENTRATIONS*. Therefore, additional sampling to develop *REPRESENTATIVE CONCENTRATIONS* will often be required after the nature and extent of contamination have been defined. Some characterization data may be used in the development of a *REPRESENTATIVE CONCENTRATION* as described in Section 2.4.2 of the tabbed section titled, “Sampling Strategies.” • A statistical analysis is appropriate only if the nature and extent of contamination, including any *HOT SPOTS*, has been adequately defined. • It is not appropriate to combine samples from *HOT SPOT* areas with samples from other areas of a property for statistical analysis. This is necessary to avoid averaging or diluting the samples that represent *HOT SPOTS*. *HOT SPOTS* must be addressed separately. See Section 2.2.1.1 of the tabbed section titled, “Sampling Strategies.”

	Section 3	**Risk Analysis – Comparison to Criteria**
		★ Statistical analysis of *FACILITY* soil concentrations for comparison to soil criteria protective of the drinking water criteria may be acceptable in limited circumstances. Sufficient data must be available to demonstrate that areas of contaminated soil above criteria are not large enough to result in groundwater concentrations in an aquifer above criteria. This may require a fairly rigorous data set that is not often practical to obtain. Similarly, statistical analysis of *FACILITY* leachate concentrations for comparison to drinking water criteria may also be acceptable in limited circumstances. • If *BACKGROUND* concentrations in soil are greater than criteria, soil data may be compared to *BACKGROUND* instead. Statistical methods for comparing to *BACKGROUND* will also vary depending on which type of *BACKGROUND* is being considered. See Statistical Guidesheet 10 and Chapter 4 of the tabbed section titled, "Statistical Methods." • Statistical analysis of *FACILITY* data is not allowed for hazardous substances present above Csat screening levels without further evaluation of risk and the extent of the area exceeding Csat. • Statistical analysis of *FACILITY* data is not allowed for hazardous substances that have criteria based on acute toxicological effects and/or physical hazards.
	Section 4	**Verification of Remediation or Closure** • **No Action Needed**: If the data evaluation completed under Sections 2 and 3 demonstrated that there are no exceedances of cleanup criteria, no remedial action is required for this pathway and consequently no additional sampling or data analysis is required under Section 4. • **Excavation**: Analytical results from verification sampling will generally be compared to Part 201 criteria on a point-by-point basis* in unsaturated soil. Numbers and locations of samples collected for verifying remediation of soil by excavation can be selected in accordance with either the tabbed section titled, "Sampling Strategies" (Sections 1.3 or 2.3 as appropriate based on size of excavation), or a DEQ-approved sampling plan. • **In situ/Ex situ Treatment**: Plans for verifying remediation or closure must be made on a case-by-case basis and must demonstrate how treatment is effective in meeting cleanup criteria. These plans may or may not depend on statistical analysis of data as allowed in Sections 2 and 3. • **Cover/Containment**: Generally soil sampling will not be used to verify remediation or closure that relies on a cover or containment. Instead, verification of remediation will involve verifying the integrity of the cover or containment structure on an ongoing basis. Groundwater sampling may be used in some cases to verify the effectiveness of the cover/containment. Verification of remediation in areas outside the cover/containment structure will be done using the options above. • If *BACKGROUND* concentrations in soil are greater than criteria, soil data may be compared to *BACKGROUND* instead. Statistical methods for comparing to *BACKGROUND* will also vary depending on which type of *BACKGROUND* is being considered. See Statistical Guidesheet 10 and Chapter 4 of the tabbed section titled, "Statistical Methods."

Additional Information:	Criteria Application Guidesheet 11; Statistical Guidesheet 1
Recommended Statistical Methods for Comparison to Criteria:	If statistical analysis is documented to be practical, the recommended statistical method is comparison of *FACILITY* data to criteria using a 95% upper confidence limit (UCL) for the mean concentration (see Chapter 3 of the tabbed section titled, "Statistical Methods"). Other statistical methods may be acceptable on a case-by-case basis.

*Professional judgment is required to interpret the significance of exceedances that are very close to criteria, or that may be associated with insignificant quantities of hazardous substances.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR SOIL DATA	**Statistical Guidesheet 12**
SOIL CRITERIA PROTECTIVE OF THE GROUNDWATER SURFACE WATER INTERFACE (GSI)	
May assist in evaluation of condition(s):	11
Applicability of Statistics	**GNP**

Statistics are generally not practical as a tool for assessing this exposure pathway because of the difficulty in projecting the impact on groundwater of hazardous substances in soil and the need for analysis of transport of hazardous substance from areas that are remote from the GSI.

Key Considerations:

Section 1

Facility Determination

- For the purposes of a BEA or initial *FACILITY* determination, property may be classified as a *FACILITY* if one or more samples contain concentrations above generic residential criteria or *BACKGROUND* concentrations, whichever is greater, provided that there is not a greater body of evidence that the property is not a *FACILITY* or leachate sample results are less than the groundwater criterion. However, if concentrations of a hazardous substance from the property are less than the *STATEWIDE DEFAULT BACKGROUND* value in Operational Memorandum #15 for that hazardous substance, the property is not a *FACILITY* with respect to that hazardous substance. For purposes other than *FACILITY* determination (e.g., remediation and/or closure), additional data will likely be required.

- If a statistical analysis is relied upon for making a *FACILITY* determination see Sections 2 and 3.

★ In certain cases, professional judgment may dictate that this pathway is not relevant due to proximity to the surface water and other factors described in Cleanup Criteria Application Guidesheet 3. In this case, these criteria are not applicable and are not the basis for a property being considered a *FACILITY*.

Section 2

Selection of Data For Statistical Analysis

★ Samples collected for the purpose of characterizing a *FACILITY* are typically biased, based on factors such as historical information, previous sampling, disposal practices, visual impacts, and aerial photos. Once the nature and extent of contamination has been defined, it is necessary to identify and/or obtain data that will allow for appropriate comparison to criteria. There are two primary considerations in determining if data sets are adequate. First, data sets must be obtained from locations that are representative of potential impacts for this migration pathway. Second, if statistics are used, data sets must contain a sufficient number of *RANDOMLY* located sample results from an appropriate area to allow for proper statistical analysis and development of *REPRESENTATIVE CONCENTRATIONS*. Therefore, additional sampling to develop *REPRESENTATIVE CONCENTRATIONS* will often be required after the nature and extent of contamination have been defined. Some characterization data may be used in the development of a *REPRESENTATIVE CONCENTRATION* as described in section 2.4.2 of the tabbed section titled, “Sampling Strategies.”

- A statistical analysis is appropriate only if the nature and extent of contamination, including any *HOT SPOTS*, has been adequately defined.

	Section 2: (Continued)	• It is not appropriate to combine samples from *HOT SPOT* areas with samples from other areas of a property for statistical analysis. This is necessary to avoid averaging or diluting the samples that represent *HOT SPOTS*. *HOT SPOTS* must be addressed separately. See section 2.2.1.1 of the tabbed section titled, "Sampling Strategies."
	Section 3	**Risk Analysis – Comparison to Criteria** ★ Statistical analysis of *FACILITY* soil or leachate concentrations for comparison to soil criteria protective of the GSI based on generic critieria or mixing zone-based criteria may be acceptable in limited circumstances, but is generally not practical. Meaningful use of statistics in these cases would require identifying a contaminated soil volume that is remote from the GSI but related to points at the GSI with a degree of precision that is generally not practical to achieve. This is because of the uncertainties associated with distribution of hazardous substances and transport to the GSI at most sites. ★ Only soil or leachate concentrations from areas that impact groundwater concentrations at the *AVERAGING AREA* may be used for statistical comparison to a soil criteria protective of the GSI which is based on chronic mixing zone-based criteria. • If DEQ approval of a response activity is being sought, a *PROPOSAL* for a statistical analysis must be submitted to the DEQ for approval to assure that data needs and/or complexities of the pathway are addressed. • If *BACKGROUND* concentrations in soil are greater than criteria, soil data may be compared to *BACKGROUND* instead. Statistical methods for comparing to *BACKGROUND* will also vary depending on which type of *BACKGROUND* is being considered. See Statistical Guidesheet 10 and Chapter 4 of the tabbed section titled, "Statistical Methods." • Statistical analysis of *FACILITY* data is not allowed for hazardous substances present above Csat screening levels without further evaluation of risk and the extent of the area exceeding Csat.
	Section 4	**Verification of Remediation or Closure** • **No Action Needed**: If the data evaluation completed under Sections 2 and 3 demonstrated that there are no exceedances of cleanup criteria, no remedial action is required for this pathway and consequently no additional sampling or data analysis is required under Section 4. • **Excavation**: Statistical analysis of *FACILITY* soil or leachate data is generally not practical. See Section 3. Analytical results from verification sampling will therefore generally be compared to Part 201 criteria on a point-by-point basis* in unsaturated soil. Numbers and locations of samples collected for point-by-point comparison can be selected in accordance with either the tabbed section titled, "Sampling Strategies" (Sections 1.3 or 2.3 as appropriate based on size of excavation), or a DEQ-approved sampling plan. If a statistical analysis is relied upon for verifying remediation or closure follow the guidance presented in Sections 2 and 3 in this Guidesheet. • **In situ/Ex situ Treatment**: Plans for verifying remediation or closure must be made on a case-by-case basis and must demonstrate how treatment is effective in meeting cleanup criteria. These plans may or may not depend on statistical analysis of data.

	Section 4: (Continued)	• **Cover/Containment**: Generally soil sampling will not be used to verify remediation or closure that relies on a cover or containment. Instead, verification of remediation will involve verifying the integrity of the cover or containment structure on an ongoing basis. Groundwater sampling may be used in some cases to verify the effectiveness of the cover/containment. Verification of remediation in areas outside the cover/containment structure will be done using the options above. ★ For all the preceding cases, it is necessary to demonstrate that groundwater at the GSI will continue to meet GSI criteria. This conclusion must be based on a demonstration that soil conditions and sources will not result in a future exceedance of GSI criteria at the GSI. • If *BACKGROUND* concentrations in soil are greater than criteria, soil data may be compared to *BACKGROUND* instead. Statistical methods for comparing to *BACKGROUND* will also vary depending on which type of *BACKGROUND* is being considered. See Statistical Guidesheet 10 and Chapter 4 of the tabbed section titled, "Statistical Methods."

Additional Information:	Criteria Application Guidesheet 12; Statistical Guidesheet 3
Recommended Statistical Methods for Comparison to Criteria:	If statistical analysis is documented to be practical, the recommended statistical method is comparison of *FACILITY* data to criteria using a 95% upper confidence limit (UCL) for the mean concentration (see Chapter 3 of the tabbed section titled, "Statistical Methods"). Other statistical methods may be acceptable on a case-by-case basis.

*Professional judgment is required to interpret the significance of exceedances that are very close to criteria, or that may be associated with insignificant quantities of hazardous substances.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR SOIL DATA	**Statistical Guidesheet 13**
GENERIC SOIL CRITERIA PROTECTIVE FOR GROUNDWATER CONTACT	
May assist in evaluation of condition(s):	10
Applicability of Statistics	**GNP**

Statistics are generally not practical as a tool for assessing this exposure pathway because of the difficulty in projecting the impact on groundwater of hazardous substances in soil and the need to assure compliance with GCC in potentially small areas.

Key Considerations:

Section 1

Facility Determination

- For the purposes of a BEA or initial *FACILITY* determination, property may be classified as a *FACILITY* if one or more samples contain concentrations above generic residential criteria or *BACKGROUND* concentrations, whichever is greater, provided that there is not a greater body of evidence that the property is not a *FACILITY* or leachate sample results are less than the groundwater criterion. However, if concentrations of a hazardous substance from the property are less than the *STATEWIDE DEFAULT BACKGROUND* value in Operational Memorandum #15 for that hazardous substance, the property is not a *FACILITY* with respect to that hazardous substance. For purposes other than *FACILITY* determination (e.g., remediation and/or closure), additional data will likely be required.
- If a statistical analysis is relied upon for making a *FACILITY* determination see Sections 2 and 3.

★ In certain cases, professional judgment may dictate that this pathway is not relevant if the depth to groundwater is greater than the depth to utilities and the depth at which other subsurface work may be performed. These factors and additional considerations are described in Cleanup Criteria Application Guidesheet 6. If the pathway is not relevant, these criteria are not applicable and are not the basis for a property being considered a *FACILITY*.

Section 2

Selection of Data For Statistical Analysis

- Samples collected for the purpose of characterizing a *FACILITY* are typically biased, based on factors such as historical information, previous sampling, disposal practices, visual impacts, and aerial photos. Once the nature and extent of contamination has been defined, it is necessary to identify and/or obtain data that will allow for appropriate comparison to criteria. There are two primary considerations in determining if data sets are adequate. First, data sets must be obtained from locations that are consistent with the exposure assumptions for the relevant land use scenario. Second, if statistics are used, data sets must contain a sufficient number of *RANDOMLY* located sample results to allow for proper statistical analysis and development of *REPRESENTATIVE CONCENTRATIONS*. Therefore, additional sampling to develop *REPRESENTATIVE CONCENTRATIONS* will often be required after the nature and extent of contamination have been defined. Some characterization data may be used in the development of a *REPRESENTATIVE CONCENTRATION* as described in section 2.4.2 of the tabbed section titled, "Sampling Strategies."
- A statistical analysis is appropriate only if the nature and extent of contamination, including any *HOT SPOTS*, has been adequately defined.

	Section 2: (Continued)	• It is not appropriate to combine samples from *HOT SPOT* areas with samples from other areas of a property for statistical analysis. This is necessary to avoid averaging or diluting the samples that represent *HOT SPOTS*. *HOT SPOTS* must be addressed separately. See section 2.2.1.1 of the tabbed section titled, "Sampling Strategies."
	Section 3	**Risk Analysis – Comparison to Criteria** ★ Since sufficient data are generally not available to allow for a statistical evaluation within the limited area that would be necessary to assure compliance with GCC at all potential exposure points in groundwater, comparison of soil data to these criteria must generally be completed on a point-by-point basis* (i.e., each concentration at each location must be compared individually to criteria). Therefore, statistical analysis of *FACILITY* soil concentrations for comparison to soil criteria protective for groundwater contact is generally not practical. Statistical analysis of *FACILITY* leachate concentrations for comparison to criteria may be acceptable in limited circumstances, but is also generally not practical. ★ In certain cases, professional judgment may dictate that this pathway is not relevant if the depth to groundwater is greater than the depth to utilities and the depth at which other subsurface work may be performed. These factors and additional considerations are described in Cleanup Criteria Application Guidesheet 6. If the pathway is not relevant, these criteria are not applicable and are not the basis for a property being considered a *FACILITY*. • If DEQ approval of a response activity is being sought, a *PROPOSAL* for a statistical analysis must be submitted to the DEQ for approval to assure that data needs and/or complexities of the pathway are addressed. • If *BACKGROUND* concentrations in soil are greater than criteria, soil data may be compared to *BACKGROUND* instead. Statistical methods for determining *BACKGROUND* concentrations will vary depending on which type of *BACKGROUND* is being considered. See Statistical Guidesheet 10 and Chapter 4 of the tabbed section titled, "Statistical Methods." • Statistical analysis of *FACILITY* data is not allowed for hazardous substances present above Csat screening levels without further evaluation of risk and the extent of the area exceeding Csat.
	Section 4	**Verification of Remediation or Closure** • **No Action Needed**: If the data evaluation completed under Sections 2 and 3 demonstrated that there are no exceedances of cleanup criteria, no remedial action is required for this pathway and consequently no additional sampling or data analysis is required under Section 4. • **Excavation**: Statistical analysis of *FACILITY* soil or leachate data is generally not practical. See Section 3. Analytical results from verification sampling will therefore generally be compared to Part 201 criteria on a point-by-point basis* in unsaturated soil. Numbers and locations of samples collected for point-by-point comparison can be selected in accordance with either the tabbed section titled, "Sampling Strategies" (Sections 1.3 or 2.3 as appropriate based on size of excavation), or a DEQ-approved sampling plan. If a statistical analysis is relied upon for verifying remediation or closure follow the guidance presented in Sections 2 and 3 of this Guidesheet.

	Section 4: (Continued)	• **In situ/Ex situ Treatment**: Plans for verifying remediation or closure must be made on a case-by-case basis and must demonstrate how treatment is effective in meeting cleanup criteria. These plans may or may not depend on statistical analysis of data. • **Cover/Containment**: Generally soil sampling will not be used to verify remediation or closure that relies on a cover or containment. Instead, verification of remediation will involve verifying the integrity of the cover or containment structure on an ongoing basis. Groundwater sampling may be used in some cases to verify the effectiveness of the cover/containment in which case groundwater data should be evaluated as described in Section 4 of Statistical Guidesheet 6. Verification of remediation in areas outside the cover/containment structure will be done using the options above. • If *BACKGROUND* concentrations in soil are greater than criteria, soil data may be compared to *BACKGROUND* instead. Statistical methods for determining *BACKGROUND* concentrations will vary depending on which type of *BACKGROUND* is being considered. See Statistical Guidesheet 10 and Chapter 4 of the tabbed section titled, "Statistical Methods."
Additional Information:		Criteria Application Guidesheet 13; Statistical Guidesheet 6
Recommended Statistical Methods for Comparison to Criteria:		If statistical analysis is documented to be practical, the recommended statistical method is comparison of *FACILITY* data to criteria using a 95% upper confidence limit (UCL) for the mean concentration (see Chapter 3 of the tabbed section titled, "Statistical Methods"). Other statistical methods may be acceptable on a case-by-case basis.

*Professional judgment is required to interpret the significance of exceedances that are very close to criteria, or that may be associated with insignificant quantities of hazardous substances.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR SOIL DATA	**Statistical Guidesheet 14**
GENERIC RESIDENTIAL AND COMMERCIAL I SOIL VOLATILIZATION TO INDOOR AIR INHALATION CRITERIA (SVIIC)	
May assist in evaluation of condition(s):	8
Applicability of Statistics	**GNP**
Statistics are generally not practical as a tool for assessing this exposure pathway because it is unlikely that there will be a sufficient number of samples available from the generic building footprint size.	

Key Considerations:

Section 1

Facility Determination

- For the purposes of a BEA or initial *FACILITY* determination, property may be classified as a *FACILITY* if one or more samples contain concentrations above generic residential criteria, provided that there is not a greater body of evidence that the property is not a *FACILITY*. For purposes other than *FACILITY* determination (e.g., remediation and/or closure), additional data will likely be required.
- If a statistical analysis is relied upon for making a *FACILITY* determination see Sections 2 and 3.

Section 2

Selection of Data For Statistical Analysis

★ Generally, only data from a 1,200 ft^2 *EXPOSURE UNIT* may be used in any particular statistical calculation.

- Samples collected for the purpose of characterizing a *FACILITY* are typically biased, based on factors such as historical information, previous sampling, disposal practices, visual impacts, and aerial photos. Once the nature and extent of contamination has been defined, it is necessary to identify and/or obtain data that will allow for appropriate comparison to criteria. There are two primary considerations in determining if data sets are adequate. First, data sets must be obtained from locations that are consistent with the exposure assumptions for the relevant land use scenario. Second, if statistics are used, data sets must contain a sufficient number of *RANDOMLY* located sample results to allow for proper statistical analysis and development of *REPRESENTATIVE CONCENTRATIONS*. Therefore, additional sampling to develop *REPRESENTATIVE CONCENTRATIONS* will often be required after the nature and extent of contamination have been defined. Some characterization data may be used in the development of a *REPRESENTATIVE CONCENTRATION* as described in Section 2.4.2 of the tabbed section titled, "Sampling Strategies."
- A statistical analysis is appropriate only if the nature and extent of contamination, including any *HOT SPOTS*, has been adequately defined.
- It is not appropriate to combine data from *HOT SPOT* areas with data from other areas of a property for statistical analysis. This is necessary to avoid averaging out or diluting the samples that represent *HOT SPOTS*. *HOT SPOTS* must be addressed separately. See Section 2.2.1.1 of the tabbed section titled, "Sampling Strategies."

★ Generally only soil data from a 1,200 ft^2 *EXPOSURE UNIT* (i.e., the building footprint) may be used in a statistical calculation for remedial compliance.

	Section 3	**Risk Analysis – Comparison to Criteria**
		★ Statistical analysis of *FACILITY* soil concentrations for comparison to residential SVIIC is generally not practical since sufficient data (i.e., a minimum of nine *RANDOMLY* located samples) are generally not available to allow for a statistical evaluation within the generic building footprint area of 1,200 ft^2. Therefore, comparisons to SVIIC must generally be completed on a point-by-point basis* (i.e., each concentration at each location must be compared individually to criteria). ★ Any statistical analysis must consider the potential for spatial variability of soil types to influence vapor migration. • If DEQ approval of a response activity is being sought, a *PROPOSAL* for a statistical analysis must be submitted to the DEQ for approval to assure that data needs and/or complexities of the pathway are addressed. • Statistical analysis of *FACILITY* data is not allowed for hazardous substances present above Csat screening levels without further evaluation of risk and the extent of the area exceeding Csat.
	Section 4	**Verification of Remediation or Closure**
		• **No Action Needed**: If the data evaluation completed under Sections 2 and 3 demonstrated that there are no exceedances of cleanup criteria, no remedial action is required for this pathway and consequently no additional sampling or data analysis is required under Section 4. • **Excavation**: Statistical analysis of *FACILITY* soil data is generally not practical. See Section 3. Analytical results from verification sampling will therefore generally be compared to Part 201 criteria on a point-by-point basis* in unsaturated soil. Numbers and locations of samples collected for point-by-point comparison can be selected in accordance with either the tabbed section titled, "Sampling Strategies" (Sections 1.3 or 2.3 as appropriate based on size of excavation), or a DEQ-approved sampling plan. If a statistical analysis is relied upon for verifying remediation or closure follow the guidance presented in Sections 2 and 3 of this Guidesheet. • **In situ/Ex situ Treatment**: Plans for verifying remediation or closure must be made on a case-by-case basis and must demonstrate how treatment is effective in meeting cleanup criteria. These plans may or may not depend on statistical analysis of data. • **Cover/Containment**: In the context of this pathway, cover/containment will typically be a vapor barrier. Generally soil sampling will not be used to verify remediation or closure that relies on a cover or containment. Verification of remediation in areas outside the cover/containment structure will be done using the other options in this section. • If *BACKGROUND* concentrations in soil are greater than criteria, soil data may be compared to *BACKGROUND* instead. Statistical methods for determining *BACKGROUND* concentrations will vary depending on which type of *BACKGROUND* is being considered. See Chapter 4 of the tabbed section titled, "Statistical Methods."

Additional Information:	Criteria Application Guidesheet 14
Recommended Statistical Methods for Comparison to Criteria:	If statistical analysis is documented to be practical, the recommended statistical method is comparison of *FACILITY* data to criteria using a 95% upper confidence limit (UCL) for the mean concentration (see Chapter 3 of the tabbed section titled, "Statistical Methods"). Other statistical methods may be acceptable on a case-by-case basis.

*Professional judgment is required to interpret the significance of exceedances that are very close to criteria, or that may be associated with insignificant quantities of hazardous substances.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR SOIL DATA	**Statistical Guidesheets 15, 16 and 17**

GENERIC RESIDENTIAL AND COMMERCIAL I INFINITE AND FINITE VOLATILE SOIL INHALATION CRITERIA (VSIC) FOR AMBIENT AIR

May assist in evaluation of condition(s):	7
Applicability of Statistics	**YES**

Statistics are applicable for evaluating this exposure pathway. Use of statistics is practical when there are adequate data sets available in the *EXPOSURE UNITS* or *EMISSION SOURCE AREAS*, as appropriate to the *FACILITY*.

Key Considerations:

Section 1

Facility Determination

- For the purposes of a BEA, or initial *FACILITY* determination, property may be classified as a *FACILITY* if one or more samples contain concentrations above generic residential, provided that there is not a greater body of evidence that the property is not a *FACILITY*. For purposes other than *FACILITY* determination (e.g., remediation and/or closure), additional data will likely be required.
- If a statistical analysis is relied upon for making a *FACILITY* determination see Sections 2 and 3.

Section 2

Selection of Data For Statistical Analysis

- Samples collected for the purpose of characterizing a *FACILITY* are typically biased, based on factors such as historical information, previous sampling, disposal practices, visual impacts, and aerial photos. Once the nature and extent of contamination has been defined, it is necessary to identify and/or obtain data that will allow for appropriate comparison to criteria. There are two primary considerations in determining if data sets are adequate. First, data sets must be obtained from locations that are consistent with the exposure assumptions for the relevant land use scenario. Second, if statistics are used, data sets must contain a sufficient number of *RANDOMLY* located sample results to allow for proper statistical analysis and development of *REPRESENTATIVE CONCENTRATIONS*. Therefore, additional sampling to develop *REPRESENTATIVE CONCENTRATIONS* will often be required after the nature and extent of contamination have been defined. Some characterization data may be used in the development of a *REPRESENTATIVE CONCENTRATION* as described in Section 2.4.2 of the tabbed section titled, "Sampling Strategies."
- A statistical analysis of soil data should be completed only if the nature and extent of contamination, including any *HOT SPOTS*, has been adequately defined.
- It is not appropriate to combine samples from *HOT SPOT* areas with samples from other areas of a property for statistical analysis. This is necessary to avoid averaging or diluting the samples that represent *HOT SPOTS*. *HOT SPOTS* must be addressed separately. See Section 2.2.1.1 of the tabbed section titled, "Sampling Strategies."
- ★ The horizontal and vertical extent of the *EMISSION SOURCE AREA* must be estimated to allow for selection of the *SOURCE SIZE MODIFIER* and infinite or finite source generic VSIC. Only data from the estimated *EMISSION SOURCE AREA* may be used in statistical analysis for comparison to criteria. See the "Part 201 Generic Soil Inhalation Criteria for Ambient Air: Technical Support Document" for information about source size characterization.

	Section 2: (Continued)	★ Characterization of the horizontal extent of contamination is necessary for both finite and infinite generic VSIC to estimate the *EMISSION SOURCE AREA* contributing to volatile emissions from soil. ★ Infinite generic VSIC are applicable to the entire contaminated vertical soil column since both surface and subsurface concentrations of hazardous substances in soil may contribute to volatile emissions. ★ Finite generic VSIC are applicable only when contamination is demonstrated to be limited to a two or five-foot vertical interval. Consequently, only data from the contaminated interval can be included in a statistical analysis. If contamination is not limited to a two or five-foot interval, infinite source VSIC are applicable. ★ A *SOURCE SIZE MODIFIER* must be selected for *EMISSION SOURCE SIZES* that are different than the assumed 1/2 acre *EMISSION SOURCE SIZE*. The *SOURCE SIZE MODIFIER* must correspond to an *EMISSION SOURCE SIZE* that is at least as large as the *EMISSION SOURCE SIZE* of the *FACILITY*. For example, if the *EMISSION SOURCE SIZE* at a *FACILITY* is at least eight acres, the generic soil inhalation criteria for a 1/2 acre *EMISSION SOURCE SIZE* is multiplied by the *SOURCE SIZE MODIFIER* for 10 acres to provide generic criteria for a 10 acre *FACILITY*. *SOURCE SIZE MODIFIERS* to adjust generic criteria for *EMISSION SOURCE SIZES* other than a 1/2 acre are provided in a table at the end of this guidesheet.
	Section 3	**Risk Analysis – Comparison to Criteria** ★ Criteria for this pathway depend on the *EMISSION SOURCE SIZE*, which must be estimated in both the horizontal and vertical dimension. Criteria shown in the cleanup criteria tables are based on a 1/2 acre *EMISSION SOURCE SIZE*. *SOURCE SIZE MODIFIERS* to adjust generic criteria for *EMISSION SOURCE SIZES* other than a 1/2 acre are provided in a table at the end of this guidesheet. For convenience, this table has been updated to include 1/4 acre and two acre *EMISSION SOURCE SIZES* for use at residential/commercial I and commercial II, III, IV and industrial land uses, respectively. Soil contamination for the VSIC pathway may occur in two general patterns that will affect the *EMISSION SOURCE SIZE* used to adjust the criteria for comparison to the *FACILITY* data: ★ **Properties or *FACILITIES* with a single *EMISSION SOURCE AREA*** If hazardous substances are detected in only a limited area within a 1/4 acre *EXPOSURE UNIT* and are not detected in other areas of the *EXPOSURE UNIT*, the *EMISSION SOURCE AREA* is equal to only the horizontal extent of the area with detectable concentrations. Only data within the *EMISSION SOURCE AREA* may be included in a statistical analysis. For an *EMISSION SOURCE AREA* that is larger than a 1/4 acre (i.e., *EXPOSURE UNIT*), soil concentrations within each 1/4 acre *EXPOSURE UNIT* must meet the VSIC adjusted for the *EMISSION SOURCE SIZE*.

Section 3: (Continued)

★ **Properties with multiple *EMISSION SOURCE AREAS***

Properties larger than a 1/4 acre may contain several small *EMISSION SOURCE AREAS*. Where hazardous substances are not detected in the areas of the property between *EMISSION SOURCE AREAS*, the final *EMISSION SOURCE SIZE* is the sum of the horizontal extent of all individual *EMISSION SOURCE AREAS*. Soil concentrations within each *EMISSION SOURCE AREA* are compared to the generic criteria adjusted for the summed area of the individual *EMISSION SOURCE AREA* sizes.

★ Statistical analysis is possible for either the *EXPOSURE UNIT* or the *EMISSION SOURCE AREA* provided that sufficient data are available as described in Section 2.

★ Nine *RANDOMLY* located samples per *EXPOSURE UNIT* or *EMISSION SOURCE AREA*, whichever is smaller, should generally be used to conduct the statistical analysis. The actual number of samples to be collected may vary based on size of the *EMISSION SOURCE AREA*. Data collected for other purposes (as for identification of nature and extent) may be used where *RANDOM* sample locations fall on or reasonably close to existing sample locations and where data will be consistent in terms of sampling and analytical methods.

- Statistical analyses must include an evaluation of the underlying statistical distribution of the data (i.e., normal, lognormal, or neither) and the level of censoring (i.e., proportion of the data below the detection limit). See the tabbed section titled, Statistical Methods." This evaluation must be completed for each hazardous substance. Additionally, the statistical methods used to compare *FACILITY* data to criteria must be selected based on statistical distribution and level of censoring.

★ Compliance with infinite generic VSIC must be demonstrated for the entire vertical soil column since both surface and subsurface soil concentrations of hazardous substances may contribute to volatile emissions.

- Since a hazardous substance will <u>not</u> volatilize more when present at concentrations greater than Csat, sample data that exceeds Csat can be included in a statistical analysis to determine compliance with the VSIC as long as the Csat exceedance is not a *HOT SPOT*.

- Statistical analysis of *FACILITY* data is not allowed for hazardous substances that have criteria based on acute toxicological effects and/or physical hazards.

Section 4

Verification of Remediation or Closure

- **No Action Needed**: If the data evaluation completed under Sections 2 and 3 demonstrated that there are no exceedances of cleanup criteria, no remedial action is required for this pathway and consequently no additional sampling or data analysis is required under Section 4.

	Section 4: (Continued)	• **Excavation**: Numbers and locations of samples collected for verifying remediation of soil can be selected in accordance with either the tabbed section titled, "Sampling Strategies" (Sections 1.3 or 2.3 as appropriate based on size of excavation), or a DEQ-approved sampling plan when a person is seeking DEQ approval of the response activity. Analytical results from verification sampling must be compared to Part 201 criteria on a point-by-point basis* unless a minimum of nine *RANDOMLY* located samples are available within the *EXPOSURE UNIT(S)* or *EMISSION SOURCE AREA*, whichever is smaller. If a statistical analysis is used, analytical results from verification sampling must be compared to Part 201 criteria as described in Sections 2 and 3. • **In situ/Ex situ Treatment**: Plans for verifying remediation or closure must be made on a case-by-case basis and must demonstrate how treatment is effective in meeting cleanup criteria. These plans may or may not depend on statistical analysis of data as allowed in Sections 2 and 3. • **Cover/Containment**: Generally soil sampling will not be used to verify Limited or Site-specific remediation or closure that relies on a cover or containment. Instead, verification of remediation will involve verifying the integrity of the cover or containment structure on an ongoing basis. Verification of remediation in areas outside the cover/containment structure will be done using the options above.
Additional Information:		Criteria Application Guidesheet 15; "Part 201 Generic Soil Inhalation Criteria for Ambient Air: Technical Support Document"
Recommended Statistical Methods for Comparison to Criteria:		Compare *FACILITY* data to criteria using a 95% upper confidence limit (UCL) for the mean concentration (see Chapter 3 of the tabbed section titled, "Statistical Methods"). Other statistical methods may be acceptable on a case-by-case basis.

*Professional judgment is required to interpret the significance of exceedances that are very close to criteria, or that may be associated with insignificant quantities of hazardous substances.

***SOURCE SIZE MODIFIERS* for Ambient Air Soil Inhalation Criteria**

Modifiers		
Source Size (ft^2 or acres)	Q/C (g/m^2-s per kg/m^3)	Modifier
400 ft^2	261.26	3.17
1000 ft^2	180.76	2.2
2000 ft^2	144.91	1.76
1/4 acre	94.56	1.15
1/2 acre	82.33	1
1 acre	71.74	0.87
2 acre	63.51	0.77
5 acre	54.62	0.66
10 acre	49.13	0.6
32 acre	41.55	0.5
100 acre	35.66	0.43

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR SOIL DATA	**Statistical Guidesheet 18**
GENERIC RESIDENTIAL AND COMMERCIAL I PARTICULATE SOIL INHALATION CRITERIA (PSIC) FOR AMBIENT AIR	
May assist in evaluation of condition(s):	7
Applicability of Statistics	**YES**
Statistics are applicable for evaluating this exposure pathway. Use of statistics is practical when there are adequate data sets available in the *EXPOSURE UNITS* or *EMISSION SOURCE AREAS*, as appropriate to the *FACILITY*.	

Key Considerations:	**Section 1**	**Facility Determination**
		• For the purposes of a BEA, or initial *FACILITY* determination, property may be classified as a *FACILITY* if one or more samples contain concentrations above generic residential criteria or *BACKGROUND* concentrations, whichever is greater, provided that there is not a greater body of evidence that the property is not a *FACILITY*. However, if concentrations of a hazardous substance from the property are less than the *STATEWIDE DEFAULT BACKGROUND* value in Operational Memorandum #15 for that hazardous substance, the property is not a *FACILITY* with respect to that hazardous substance. For purposes other than *FACILITY* determination (e.g., remediation and/or closure), additional data will likely be required. • If a statistical analysis is relied upon for making a *FACILITY* determination see Sections 2 and 3.
	Section 2	**Selection of Data For Statistical Analysis**
		• Samples collected for the purpose of characterizing a *FACILITY* are typically biased, based on factors such as historical information, previous sampling, disposal practices, visual impacts, and aerial photos. Once the nature and extent of contamination has been defined, it is necessary to identify and/or obtain data that will allow for appropriate comparison to criteria. There are two primary considerations in determining if data sets are adequate. First, data sets must be obtained from locations that are consistent with the exposure assumptions for the relevant land use scenario. Second, if statistics are used, data sets must contain a sufficient number of *RANDOMLY* located sample results to allow for proper statistical analysis and development of *REPRESENTATIVE CONCENTRATIONS*. Therefore, additional sampling to develop *REPRESENTATIVE CONCENTRATIONS* will often be required after the nature and extent of contamination have been defined. Some characterization data may be used in the development of a *REPRESENTATIVE CONCENTRATION* as described in section 2.4.2 of the tabbed section titled, “Sampling Strategies.” • A statistical analysis of soil data should be completed only if the nature and extent of contamination, including any *HOT SPOTS*, has been adequately defined. • It is not appropriate to combine samples from *HOT SPOT* areas with samples from other areas of a property for statistical analysis. This is necessary to avoid averaging or diluting the samples that represent *HOT SPOTS*. *HOT SPOTS* must be addressed separately. See section 2.2.1.1 of the tabbed section titled, “Sampling Strategies.”

	Section 2: (Continued)	★ A *SOURCE SIZE MODIFIER* must be selected for *EMISSION SOURCE SIZES* that are different than the assumed 1/2 acre *EMISSION SOURCE SIZE*. The *SOURCE SIZE MODIFIER* must correspond to an *EMISSION SOURCE SIZE* that is at least as large as the *EMISSION SOURCE SIZE* of the *FACILITY*. For example, if the *EMISSION SOURCE SIZE* at a *FACILITY* is at least eight acres, the generic soil inhalation criteria for a 1/2 acre *EMISSION SOURCE SIZE* is multiplied by the *SOURCE SIZE MODIFIER* for 10 acres to provide generic criteria for a 10 acre *FACILITY*. *SOURCE SIZE MODIFIERS* to adjust generic criteria for *EMISSION SOURCE SIZES* other than a 1/2 acre are provided in a table at the end of this guidesheet.
	Section 3	**Risk Analysis – Comparison to Criteria** ★ Criteria for this pathway depend on the *EMISSION SOURCE SIZE*, which must be estimated in both the horizontal and vertical dimension. Criteria shown in the cleanup criteria tables are based on a 1/2 acre *EMISSION SOURCE SIZE*. *SOURCE SIZE MODIFIERS* to adjust generic criteria for *EMISSION SOURCE SIZES* other than a 1/2 acre are provided in a table at the end of this guidesheet. For convenience, this table has been updated to include 1/4 acre and two acre *EMISSION SOURCE SIZES* for use at residential/commercial I and commercial II, III, IV and industrial land uses, respectively. Soil contamination for the PSIC pathway may occur in two general patterns that will affect the *EMISSION SOURCE SIZE* used to adjust the criteria for comparison to the *FACILITY* data: ★ **Properties or *FACILITIES* with a single *EMISSION SOURCE AREA*** If hazardous substances are detected in only a limited area within a 1/4 acre *EXPOSURE UNIT* and are not detected in other areas of the *EXPOSURE UNIT*, the *EMISSION SOURCE AREA* is equal to only the horizontal extent of the area with detectable concentrations. Only data within the *EMISSION SOURCE AREA* may be included in a statistical analysis. For an *EMISSION SOURCE AREA* that is larger than a 1/4 acre (i.e., *EXPOSURE UNIT*), soil concentrations within each 1/4 acre *EXPOSURE UNIT* must meet the PSIC adjusted for the *EMISSION SOURCE SIZE.* ★ **Properties with multiple *EMISSION SOURCE AREAS*** Properties larger than a 1/4 acre may contain several small *EMISSION SOURCE AREAS*. Where hazardous substances are not detected in the areas of the property between *EMISSION SOURCE AREAS*, the final *EMISSION SOURCE SIZE* is the sum of the horizontal extent of all individual *EMISSION SOURCE AREAS*. Soil concentrations within each *EMISSION SOURCE AREA* are compared to the generic criteria adjusted for the summed area of the individual *EMISSION SOURCE AREA* sizes. ★ Statistical analysis is possible for either the *EXPOSURE UNIT* or the *EMISSION SOURCE AREA* provided that sufficient data are available as described in Section 2.

	Section 3: (Continued)	★ Nine *RANDOMLY* located samples per *EXPOSURE UNIT* or *EMISSION SOURCE AREA*, whichever is smaller, should generally be used to conduct the statistical analysis. The actual number of samples to be collected may vary based on size of the *EMISSION SOURCE AREA*. Data collected for other purposes (as for identification of nature and extent) may be used where *RANDOM* sample locations fall on or reasonably close to existing sample locations and where data will be consistent in terms of sampling and analytical methods. • Statistical analyses must include an evaluation of the underlying statistical distribution of the data (i.e., normal, lognormal, or neither) and the level of censoring (i.e., proportion of the data below the detection limit). See the tabbed section titled, Statistical Methods." This evaluation must be completed for each hazardous substance. Additionally, the statistical methods used to compare *FACILITY* data to criteria must be selected based on statistical distribution and level of censoring. ★ Compliance with infinite generic PSIC must be demonstrated for the entire vertical soil column since hazardous substances in subsurface soil may contribute to emissions if moved to the surface in the future. • Statistical analysis of *FACILITY* data is not allowed for hazardous substances that have criteria based on acute toxicological effects and/or physical hazards. • If *BACKGROUND* concentrations in soil are greater than criteria, soil data may be compared to *BACKGROUND* instead. Statistical methods for determining *BACKGROUND* concentrations will vary depending on which type of *BACKGROUND* is being considered. See Statistical Guidesheet 10 and Chapter 4 of the tabbed section titled, "Statistical Methods."
	Section 4	**Verification of Remediation or Closure** • **No Action Needed**: If the data evaluation completed under Sections 2 and 3 demonstrated that there are no exceedances of cleanup criteria, no remedial action is required for this pathway and consequently no additional sampling or data analysis is required under Section 4. • **Excavation**: Numbers and locations of samples collected for verifying remediation of soil can be selected in accordance with either the tabbed section titled, "Sampling Strategies" (Sections 1.3 or 2.3 as appropriate based on size of excavation), or a DEQ-approved sampling plan when a person is seeking DEQ approval of the response activity. Analytical results from verification sampling must be compared to Part 201 criteria on a point-by-point basis* unless a minimum of nine *RANDOMLY* located samples are available within the *EXPOSURE UNIT(S)* or *EMISSION SOURCE AREA*, whichever is smaller. If a statistical analysis is used, analytical results from verification sampling must be compared to Part 201 criteria as described in Sections 2 and 3. • **In situ/Ex situ Treatment**: Plans for verifying remediation or closure must be made on a case-by-case basis and must demonstrate how treatment is effective in meeting cleanup criteria. These plans may or may not depend on statistical analysis of data as allowed in Sections 2 and 3.

	Section 4: (Continued)	• **Cover/Containment**: Generally soil sampling will not be used to verify Limited or Site-specific remediation or closure that relies on a cover or containment. Instead, verification of remediation will involve verifying the integrity of the cover or containment structure on an ongoing basis. Verification of remediation in areas outside the cover/containment structure will be done using the options above.
Additional Information:		Criteria Application Guidesheet 18; "Part 201 Generic Soil Inhalation Criteria for Ambient Air: Technical Support Document"
Recommended Statistical Methods for Comparison to Criteria:		Compare *FACILITY* data to criteria using a 95% upper confidence limit (UCL) for the mean concentration (see Chapter 3 of the tabbed section titled, "Statistical Methods"). Other statistical methods may be acceptable on a case-by-case basis.

*Professional judgment is required to interpret the significance of exceedances that are very close to criteria, or that may be associated with insignificant quantities of hazardous substances.

***SOURCE SIZE MODIFIERS* for Ambient Air Soil Inhalation Criteria**

Modifiers		
Source Size (ft^2 or acres)	Q/C (g/m^2-s per kg/m^3)	Modifier
400 ft^2	261.26	3.17
1000 ft^2	180.76	2.2
2000 ft^2	144.91	1.76
1/4 acre	94.56	1.15
1/2 acre	82.33	1
1 acre	71.74	0.87
2 acre	63.51	0.77
5 acre	54.62	0.66
10 acre	49.13	0.6
32 acre	41.55	0.5
100 acre	35.66	0.43

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR SOIL DATA	**Statistical Guidesheet 19**
GENERIC RESIDENTIAL AND COMMERCIAL I DIRECT CONTACT CRITERIA (DCC)	
May assist in evaluation of condition(s):	6
Applicability of Statistics	**YES**

Statistics are applicable for evaluating this exposure pathway. Use of statistics is practical when there are adequate data sets available for the *EXPOSURE UNITS*.

Key Considerations:

Section 1

Facility Determination

- For the purposes of a BEA, or initial *FACILITY* determination, property may be classified as a *FACILITY* if one or more samples contain concentrations above generic residential criteria or *BACKGROUND* concentrations, whichever is greater, provided that there is not a greater body of evidence that the property is not a *FACILITY*. However, if concentrations of a hazardous substance from the property are less than the *STATEWIDE DEFAULT BACKGROUND* value in Operational Memorandum #15 for that hazardous substance, the property is not a *FACILITY* with respect to that hazardous substance. For purposes other than *FACILITY* determination (e.g., remediation and/or closure), additional data will likely be required.
- If a statistical analysis is relied upon for making a *FACILITY* determination see Sections 2 and 3.

Section 2

Selection of Data For Statistical Analysis

- Samples collected for the purpose of characterizing a *FACILITY* are typically biased, based on factors such as historical information, previous sampling, disposal practices, visual impacts, and aerial photos. Once the nature and extent of contamination has been defined, it is necessary to identify and/or obtain data that will allow for appropriate comparison to criteria. There are two primary considerations in determining if data sets are adequate. First, data sets must be obtained from locations that are consistent with the exposure assumptions for the relevant land use scenario. Second, if statistics are used, data sets must contain a sufficient number of *RANDOMLY* located sample results to allow for proper statistical analysis and development of *REPRESENTATIVE CONCENTRATIONS*. Therefore, additional sampling to develop *REPRESENTATIVE CONCENTRATIONS* will often be required after the nature and extent of contamination have been defined. Some characterization data may be used in the development of a *REPRESENTATIVE CONCENTRATION* as described in Section 2.4.2 of the tabbed section titled, “Sampling Strategies.”
- A statistical analysis of soil data should be completed only if the nature and extent of contamination, including any *HOT SPOTS*, has been adequately defined.
- It is not appropriate to combine samples from *HOT SPOT* areas with samples from other areas of a property for statistical analysis. This is necessary to avoid averaging or diluting the samples that represent *HOT SPOTS*. *HOT SPOTS* must be addressed separately. See Section 2.2.1.1 of the tabbed section titled, “Sampling Strategies.”

★ Generally only soil data from a 1/4 acre *EXPOSURE UNIT* may be used in a statistical calculation for remedial compliance.

	Section 2: (Continued)	★ Soil data from an *EXPOSURE UNIT* that reflects current human activity patterns may be used in a statistical calculation for Due Care compliance. ★ Compliance with these criteria must be demonstrated separately for surface and subsurface soils unless there is little variability between surface and subsurface data. Surface soils are typically defined as the top six inches of the soil column. However, if contamination is predominantly located at the immediate surface (such as through air deposition of hazardous substances), surface soil samples should represent the immediate surface (e.g., top one inch). ★ Subsurface soils should be evaluated in the same manner as surface soils; however, larger *EXPOSURE UNITS* and/or fewer samples may be acceptable if characterization of the property indicates that contamination is predominantly at the surface. ★ *EXPOSURE UNITS* larger than the standard 1/4 acre may be used for both Due Care and Remedial Compliance if it has been demonstrated that there is little variability among concentrations of hazardous substances in the *EXPOSURE UNIT* to be evaluated.
	Section 3	**Risk Analysis – Comparison to Criteria** ★ For remedial compliance, the *FACILITY* must generally be divided into 1/4 acre *EXPOSURE UNITS* for comparison to generic residential criteria. *EXPOSURE UNIT* size can be different for surface and subsurface soil. Areas classified as *HOT SPOTS* must be evaluated separately. A minimum of nine *RANDOMLY* located samples per *EXPOSURE UNIT* (considering surface soil and subsurface soil separately) are required to conduct the statistical analysis. This number is based on statistical considerations only. Additional samples may be necessary to adequately characterize and represent spatial variability in the *EXPOSURE UNIT* depending on such factors as soil type and size of the *EXPOSURE UNIT*. ★ *EXPOSURE UNITS* for Due Care should be based on exposures currently occurring and reasonably likely to occur based on human activity patterns at the *FACILITY*. If activities are concentrated in an area smaller than the standard *EXPOSURE UNIT*, *EXPOSURE UNITS* smaller than 1/4 acre should be used. • Statistical analyses must include an evaluation of the underlying statistical distribution of the data (i.e., normal, lognormal, or neither) and the level of censoring (i.e., proportion of the data below the detection limit). See the tabbed section titled, “Statistical Methods.” This evaluation must be completed for each hazardous substance. The statistical methods used to compare *FACILITY* data to criteria must be selected based on statistical distribution and level of censoring. • If *BACKGROUND* concentrations in soil are greater than criteria, soil data may be compared to *BACKGROUND* instead. Statistical methods for determining *BACKGROUND* concentrations will vary depending on which type of *BACKGROUND* is being considered. See Statistical Guidesheet 10 and Chapter 4 of the tabbed section titled, “Statistical Methods.” • Statistical analysis of *FACILITY* data is not allowed for hazardous substances present above Csat screening levels without further evaluation of risk and the extent of the area exceeding Csat. • Statistical analysis of *FACILITY* data is not allowed for hazardous substances that have criteria based on acute toxicological effects and/or physical hazards.

	Section 4	**Verification of Remediation or Closure**
		• **No Action Needed**: If the data evaluation completed under Sections 2 and 3 demonstrated that there are no exceedances of cleanup criteria, no remedial action is required for this pathway and consequently no additional sampling or data analysis is required under Section 4. • **Excavation**: Numbers and locations of samples collected for verifying remediation of soil can be selected in accordance with either the tabbed section titled, "Sampling Strategies" (Sections 1.3 or 2.3 as appropriate based on size of excavation), or a DEQ-approved sampling plan when a person is seeking DEQ approval of the response activity. Analytical results from verification sampling must be compared to Part 201 criteria on a point-by-point basis* unless a minimum of nine *RANDOMLY* located samples are available within the *EXPOSURE UNIT(S).* If a statistical analysis is used, analytical results from verification sampling must be compared to Part 201 criteria as described in Sections 2 and 3. • **In situ/Ex situ Treatment**: Plans for verifying remediation or closure must be made on a case-by-case basis and must demonstrate how treatment is effective in meeting cleanup criteria. These plans may or may not depend on statistical analysis of data as allowed in Sections 2 and 3. • **Cover/Containment**: Generally soil sampling will not be used to verify Limited or Site-specific remediation or closure that relies on a cover or containment. Instead, verification of remediation will involve verifying the integrity of the cover or containment structure on an ongoing basis. Verification of remediation in areas outside the cover/containment structure will be done using the options above. • If *BACKGROUND* concentrations in soil are greater than criteria, soil data may be compared to *BACKGROUND* instead. Statistical methods for determining *BACKGROUND* concentrations will vary depending on which type of *BACKGROUND* is being considered. See Statistical Guidesheet 10 and Chapter 4 of the tabbed section titled, "Statistical Methods."
Additional Information:		Criteria Application Guidesheet 19
Recommended Statistical Methods for Comparison to Criteria:		Compare *FACILITY* data to criteria using a 95% upper confidence limit (UCL) for the mean concentration (see Chapter 3 of the tabbed section titled, "Statistical Methods"). Other statistical methods may be acceptable on a case-by-case basis.

*Professional judgment is required to interpret the significance of exceedances that are very close to criteria, or that may be associated with insignificant quantities of hazardous substances.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR SOIL DATA	Statistical Guidesheet 20
GENERIC SOIL SATURATION (CSAT) SCREENING LEVELS	
May assist in evaluation of condition(s):	1 and 6-12
Applicability of Statistics	**Pathway Dependent**
See the Statistical Guidesheet for the exposure pathway where the cleanup criterion defaults to Csat to determine the applicability of statistics.	

Key Considerations:	**Section 1**	**Facility Determination**
		• See the Statistical Guidesheet for the generic criteria that defaults to the Csat screening level.
	Section 2	**Selection of Data For Statistical Analysis**
		• See the Statistical Guidesheet for the generic criteria that defaults to the Csat screening level. • Data that are greater than Csat should not be included in a statistical analysis unless a site-specific evaluation has shown that there is no free-phase hazardous substance. This does not apply to the generic volatile soil inhalation criteria (VSIC). See Section 3 of Statistical Guidesheets 15, 16 and 17 and 23, 24 and 25 for guidance in conducting statistical analysis of data with concentrations greater than Csat.
	Section 3	**Risk Analysis – Comparison to Criteria**
		• See Section 2.
	Section 4	**Verification of Remediation or Closure**
		• See Section 2.

Additional Information:	Criteria Application Guidesheet 20 and A, and Appendix A; Part 201 Generic Soil Saturation Screening Concentrations: Technical Support Document.
Recommended Statistical Methods for Comparison to Criteria:	See Statistical Guidesheet 7 for relevant exposure pathways. Pathway dependent.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR **SOIL** DATA	Statistical Guidesheet 21
GENERIC SOIL CRITERIA PROTECTIVE OF COMMERCIAL II, III, IV AND INDUSTRIAL DRINKING WATER	
May assist in evaluation of condition(s):	9
Applicability of Statistics	**GNP**
Statistics are generally not practical as a tool for assessing this exposure pathway because of the difficulty in projecting the impact on groundwater of hazardous substances in soil and the need to assure that drinking water cleanup criteria are met at all points in the aquifer.	

Key Considerations:

Section 1

Facility Determination

- Not applicable.

Section 2

Selection of Data For Statistical Analysis

- Samples collected for the purpose of characterizing a *FACILITY* are typically biased, based on factors such as historical information, previous sampling, disposal practices, visual impacts, and aerial photos. Once the nature and extent of contamination has been defined, it is necessary to identify and/or obtain data that will allow for appropriate comparison to criteria. There are two primary considerations in determining if data sets are adequate. First, data sets must be obtained from locations that are consistent with the exposure assumptions for the relevant land use scenario. Second, if statistics are used, data sets must contain a sufficient number of *RANDOMLY* located sample results to allow for proper statistical analysis and development of *REPRESENTATIVE CONCENTRATIONS*. Therefore, additional sampling to develop *REPRESENTATIVE CONCENTRATIONS* will often be required after the nature and extent of contamination have been defined. Some characterization data may be used in the development of a *REPRESENTATIVE CONCENTRATION* as described in Section 2.4.2 of the tabbed section titled, "Sampling Strategies."

- A statistical analysis is appropriate only if the nature and extent of contamination, including any *HOT SPOTS*, has been adequately defined.

- It is not appropriate to combine samples from *HOT SPOT* areas with samples from other areas of a property for statistical analysis. This is necessary to avoid averaging or diluting the samples that represent *HOT SPOTS*. *HOT SPOTS* must be addressed separately. See Section 2.2.1.1 of the tabbed section titled, "Sampling Strategies."

Section 3

Risk Analysis – Comparison to Criteria

★ Statistical analysis of *FACILITY* soil concentrations for comparison to soil criteria protective of the drinking water criteria may be acceptable in limited circumstances. Sufficient data must be available to demonstrate that areas of contaminated soil above criteria are not large enough to result in groundwater concentrations in an aquifer above criteria. This may require a fairly rigorous data set that is not often practical to obtain. Similarly, statistical analysis of *FACILITY* leachate concentrations for comparison to drinking water criteria may also be acceptable in limited circumstances.

	Section 3: (Continued)	• If *BACKGROUND* concentrations in soil are greater than criteria, soil data may be compared to *BACKGROUND* instead. Statistical methods for comparing to *BACKGROUND* will also vary depending on which type of *BACKGROUND* is being considered. See Statistical Guidesheet 10 and Chapter 4 of the tabbed section titled, "Statistical Methods." • Statistical analysis of *FACILITY* data is not allowed for hazardous substances present above Csat screening levels without further evaluation of risk and the extent of the area exceeding Csat. • Statistical analysis of *FACILITY* data is not allowed for hazardous substances that have criteria based on acute toxicological effects and/or physical hazards.
	Section 4	**Verification of Remediation or Closure** • **No Action Needed**: If the data evaluation completed under Sections 2 and 3 demonstrated that there are no exceedances of cleanup criteria, no remedial action is required for this pathway and consequently no additional sampling or data analysis is required under Section 4. • **Excavation**: Analytical results from verification sampling will generally be compared to Part 201 criteria on a point-by-point basis* in unsaturated soil. Numbers and locations of samples collected for verifying remediation of soil by excavation can be selected in accordance with either the tabbed section titled, "Sampling Strategies" (Sections 1.3 or 2.3 as appropriate based on size of excavation), or a DEQ-approved sampling plan. • **In situ/Ex situ Treatment**: Plans for verifying remediation or closure must be made on a case-by-case basis and must demonstrate how treatment is effective in meeting cleanup criteria. These plans may or may not depend on statistical analysis of data as allowed in Sections 2 and 3. • **Cover/Containment**: Generally soil sampling will not be used to verify remediation or closure that relies on a cover or containment. Instead, verification of remediation will involve verifying the integrity of the cover or containment structure on an ongoing basis. Groundwater sampling may be used in some cases to verify the effectiveness of the cover/containment. Verification of remediation in areas outside the cover/containment structure will be done using the options above. • If *BACKGROUND* concentrations in soil are greater than criteria, soil data may be compared to *BACKGROUND* instead. Statistical methods for comparing to *BACKGROUND* will also vary depending on which type of *BACKGROUND* is being considered. See Statistical Guidesheet 10 and Chapter 4 of the tabbed section titled, "Statistical Methods."

Additional Information:	Criteria Application Guidesheet 21; Statistical Guidesheet 2
Recommended Statistical Methods for Comparison to Criteria:	If statistical analysis is documented to be practical, the recommended statistical method is comparison of *FACILITY* data to criteria using a 95% upper confidence limit (UCL) for the mean concentration (see Chapter 3 of the tabbed section titled, "Statistical Methods"). Other statistical methods may be acceptable on a case-by-case basis.

*Professional judgment is required to interpret the significance of exceedances that are very close to criteria, or that may be associated with insignificant quantities of hazardous substances.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR SOIL DATA	Statistical Guidesheet 22

GENERIC COMMERCIAL II, III, IV AND INDUSTRIAL SOIL VOLATILIZATION TO INDOOR AIR INHALATION CRITERIA (SVIIC)

May assist in evaluation of condition(s):	8
Applicability of Statistics	**GNP**

Statistics are generally not practical as a tool for assessing this exposure pathway because it is unlikely that there will be a sufficient number of samples available from the generic building footprint size.

Key Considerations:

Section 1

Facility Determination

- Not applicable.

Section 2

Selection of Data For Statistical Analysis

- Samples collected for the purpose of characterizing a *FACILITY* are typically biased, based on factors such as historical information, previous sampling, disposal practices, visual impacts, and aerial photos. Once the nature and extent of contamination has been defined, it is necessary to identify and/or obtain data that will allow for appropriate comparison to criteria. There are two primary considerations in determining if data sets are adequate. First, data sets must be obtained from locations that are consistent with the exposure assumptions for the relevant land use scenario. Second, if statistics are used, data sets must contain a sufficient number of *RANDOMLY* located sample results to allow for proper statistical analysis and development of *REPRESENTATIVE CONCENTRATIONS*. Therefore, additional sampling to develop *REPRESENTATIVE CONCENTRATIONS* will often be required after the nature and extent of contamination have been defined. Some characterization data may be used in the development of a *REPRESENTATIVE CONCENTRATION* as described in Section 2.4.2 of the tabbed section titled, "Sampling Strategies."

- A statistical analysis is appropriate only if the nature and extent of contamination, including any *HOT SPOTS*, has been adequately defined.

- It is not appropriate to combine data from *HOT SPOT* areas with data from other areas of a property for statistical analysis. This is necessary to avoid averaging out or diluting the samples that represent *HOT SPOTS*. *HOT SPOTS* must be addressed separately. See Section 2.2.1.1 of the tabbed section titled, "Sampling Strategies."

★ Generally only soil data from a 4,000 ft^2 *EXPOSURE UNIT* (i.e., the building footprint) may be used in a statistical calculation for remedial compliance.

Section 3

Risk Analysis – Comparison to Criteria

★ Statistical analysis of *FACILITY* soil concentrations for comparison to residential SVIIC is generally not practical since sufficient data (i.e., a minimum of nine *RANDOMLY* located samples) are generally not available to allow for a statistical evaluation within the generic building footprint area of 4,000 ft^2. Therefore, comparisons to SVIIC must generally be completed on a point-by-point basis* (i.e., each concentration at each location must be compared individually to criteria).

	Section 3: (Continued)	★ Any statistical analysis must consider the potential for spatial variability of soil types to influence vapor migration. • If DEQ approval of a response activity is being sought, a *PROPOSAL* for a statistical analysis must be submitted to the DEQ for approval to assure that data needs and/or complexities of the pathway are addressed. • Statistical analysis of *FACILITY* data is not allowed for hazardous substances present above Csat screening levels without further evaluation of risk and the extent of the area exceeding Csat.
	Section 4	**Verification of Remediation or Closure** • **No Action Needed**: If the data evaluation completed under Sections 2 and 3 demonstrated that there are no exceedances of cleanup criteria, no remedial action is required for this pathway and consequently no additional sampling or data analysis is required under Section 4. • **Excavation**: Statistical analysis of *FACILITY* soil data is generally not practical. See Section 3. Analytical results from verification sampling will therefore generally be compared to Part 201 criteria on a point-by-point basis* in unsaturated soil. Numbers and locations of samples collected for point-by-point comparison can be selected in accordance with either the tabbed section titled, "Sampling Strategies" (Sections 1.3 or 2.3 as appropriate based on size of excavation), or a DEQ-approved sampling plan. If a statistical analysis is relied upon for verifying remediation or closure follow the guidance presented in Sections 2 and 3 of this Guidesheet. • **In situ/Ex situ Treatment**: Plans for verifying remediation or closure must be made on a case-by-case basis and must demonstrate how treatment is effective in meeting cleanup criteria. These plans may or may not depend on statistical analysis of data. • **Cover/Containment**: In the context of this pathway, cover/containment will typically be a vapor barrier. Generally soil sampling will not be used to verify remediation or closure that relies on a cover or containment. Verification of remediation in areas outside the cover/containment structure will be done using the options above.
Additional Information:		Criteria Application Guidesheet 22
Recommended Statistical Methods for Comparison to Criteria:		If statistical analysis is documented to be practical, the recommended statistical method is comparison of *FACILITY* data to criteria using a 95% upper confidence limit (UCL) for the mean concentration (see Chapter 3 of the tabbed section titled, "Statistical Methods"). Other statistical methods may be acceptable on a case-by-case basis.

*Professional judgment is required to interpret the significance of exceedances that are very close to criteria, or that may be associated with insignificant quantities of hazardous substances.

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR SOIL DATA	**Statistical Guidesheets 23, 24 and 25**

GENERIC COMMERCIAL II, III, IV AND INDUSTRIAL INFINITE SOURCE VOLATILE SOIL INHALATION CRITERIA (VSIC) FOR AMBIENT AIR

May assist in evaluation of condition(s):	7
Applicability of Statistics	**YES**

Statistics are applicable for evaluating this exposure pathway. Use of statistics is practical when there are adequate data sets available in the *EXPOSURE UNITS* or *EMISSION SOURCE AREAS*, as appropriate to the *FACILITY*.

Key Considerations:

Section 1

Facility Determination

- Not applicable.

Section 2

Selection of Data For Statistical Analysis

- Samples collected for the purpose of characterizing a *FACILITY* are typically biased, based on factors such as historical information, previous sampling, disposal practices, visual impacts, and aerial photos. Once the nature and extent of contamination has been defined, it is necessary to identify and/or obtain data that will allow for appropriate comparison to criteria. There are two primary considerations in determining if data sets are adequate. First, data sets must be obtained from locations that are consistent with the exposure assumptions for the relevant land use scenario. Second, if statistics are used, data sets must contain a sufficient number of *RANDOMLY* located sample results to allow for proper statistical analysis and development of *REPRESENTATIVE CONCENTRATIONS*. Therefore, additional sampling to develop *REPRESENTATIVE CONCENTRATIONS* will often be required after the nature and extent of contamination have been defined. Some characterization data may be used in the development of a *REPRESENTATIVE CONCENTRATION* as described in Section 2.4.2 of the tabbed section titled, "Sampling Strategies."

- A statistical analysis of soil data should be completed only if the nature and extent of contamination, including any *HOT SPOTS*, has been adequately defined.

- It is not appropriate to combine samples from *HOT SPOT* areas with samples from other areas of a property for statistical analysis. This is necessary to avoid averaging or diluting the samples that represent *HOT SPOTS*. *HOT SPOTS* must be addressed separately. See Section 2.2.1.1 of the tabbed section titled, "Sampling Strategies."

★ The horizontal and vertical extent of the *EMISSION SOURCE AREA* must be estimated to allow for selection of the *SOURCE SIZE MODIFIER* and infinite or finite source generic VSIC. Only data from the estimated *EMISSION SOURCE AREA* may be used in statistical analysis for comparison to criteria. See the "Part 201 Generic Soil Inhalation Criteria for Ambient Air: Technical Support Document" for information about source size characterization.

★ Characterization of the horizontal extent of contamination is necessary for both finite and infinite generic VSIC to estimate the *EMISSION SOURCE AREA* contributing to volatile emissions from soil.

Section 2: (Continued)

★ Infinite generic VSIC are applicable to the entire contaminated vertical soil column since both surface and subsurface soil concentrations of hazardous substances may contribute to volatile emissions.

★ For an *EMISSION SOURCE AREA* that is larger than two acres (i.e., *EXPOSURE UNIT*), soil concentrations within each two acre *EXPOSURE UNIT* must meet the VSIC adjusted for the *EMISSION SOURCE SIZE*.

★ A *SOURCE SIZE MODIFIER* must be selected for *EMISSION SOURCE SIZES* that are different than the assumed 1/2 acre *EMISSION SOURCE SIZE*. The *SOURCE SIZE MODIFIER* must correspond to an *EMISSION SOURCE SIZE* that is at least as large as the *EMISSION SOURCE SIZE* of the *FACILITY*. For example, if the *EMISSION SOURCE SIZE* at a *FACILITY* is at least eight acres, the generic soil inhalation criteria for a 1/2 acre *EMISSION SOURCE SIZE* is multiplied by the *SOURCE SIZE MODIFIER* for 10 acres to provide generic criteria for a 10 acre *FACILITY*. *SOURCE SIZE MODIFIERS* to adjust generic criteria for *EMISSION SOURCE SIZES* other than a 1/2 acre are provided in a table at the end of this guidesheet.

Section 3

Risk Analysis – Comparison to Criteria

★ Criteria for this pathway depend on the *EMISSION SOURCE SIZE*, which must be estimated in both the horizontal and vertical dimension. Criteria shown in the cleanup criteria tables are based on a 1/2 acre *EMISSION SOURCE SIZE*. *SOURCE SIZE MODIFIERS* to adjust generic criteria for *EMISSION SOURCE SIZES* other than a 1/2 acre are provided in a table at the end of this guidesheet. For convenience, this table has been updated to include 1/4 acre and two acre *EMISSION SOURCE SIZES* for use at residential/commercial I and commercial II, III, IV and industrial land uses, respectively.

Soil contamination for the VSIC pathway may occur in two general patterns that will affect the *EMISSION SOURCE SIZE* used to adjust the criteria for comparison to the *FACILITY* data:

★ **Properties or *FACILITIES* with a single *EMISSION SOURCE AREA***

If hazardous substances are detected in only a limited area within a two acre *EXPOSURE UNIT* and are not detected in other areas of the *EXPOSURE UNIT*, the *EMISSION SOURCE AREA* is equal to only the horizontal extent of the area with detectable concentrations. Only data within the *EMISSION SOURCE AREA* may be included in a statistical analysis.

For an *EMISSION SOURCE AREA* that is larger than two acres (i.e., *EXPOSURE UNIT*), soil concentrations within each two acre *EXPOSURE UNIT* must meet the VSIC adjusted for the *EMISSION SOURCE SIZE*.

★ **Properties with multiple *EMISSION SOURCE AREAS***

Properties larger than a two acre may contain several small *EMISSION SOURCE AREAS*. Where hazardous substances are not detected in the areas of the property between *EMISSION SOURCE AREAS*, the final *EMISSION SOURCE SIZE* is the sum of the horizontal extent of all individual *EMISSION SOURCE AREAS*. Soil concentrations within each *EMISSION SOURCE AREA* are compared to the generic criteria adjusted for the summed area of the individual *EMISSION SOURCE AREA* sizes.

	Section 3: (Continued)	★ Generally only soil data from a two acre *EXPOSURE UNIT* may be used in a statistical calculation for remedial compliance unless the property is smaller than two acres and the *FACILITY* is confined to the property. In that case, the *EXPOSURE UNIT* size will be same as the property size. <u>However, in cases where the *EMISSION SOURCE AREA* is smaller than two acres only soil data from the *EMISSION SOURCE AREA* may be used in a statistical calculation</u>. ★ Statistical analysis is possible for either the *EXPOSURE UNIT* or the *EMISSION SOURCE AREA* provided that sufficient data are available as described in Section 2. ★ Nine *RANDOMLY* located samples per *EXPOSURE UNIT* or *EMISSION SOURCE AREA*, whichever is smaller, should generally be used to conduct the statistical analysis. The actual number of samples to be collected may vary based on size of the *EMISSION SOURCE AREA*. Data collected for other purposes (as for identification of nature and extent) may be used where *RANDOM* sample locations fall on or reasonably close to existing sample locations and where data will be consistent in terms of sampling and analytical methods. • Statistical analyses must include an evaluation of the underlying statistical distribution of the data (i.e., normal, lognormal, or neither) and the level of censoring (i.e., proportion of the data below the detection limit). See the tabbed section titled, "Statistical Methods." This evaluation must be completed for each hazardous substance. Additionally, the statistical methods used to compare *FACILITY* data to criteria must be selected based on statistical distribution and level of censoring. ★ Compliance with infinite generic VSIC must be demonstrated for the entire vertical soil column since both surface and subsurface soil concentrations of hazardous substances may contribute to volatile emissions. • Since a hazardous substance will <u>not</u> volatilize more when present at concentrations greater than Csat, sample data that exceeds Csat can be included in a statistical analysis to determine compliance with the VSIC as long as the Csat exceedance is not a *HOT SPOT*. • Statistical analysis of *FACILITY* data is not allowed for hazardous substances that have criteria based on acute toxicological effects and/or physical hazards.
	Section 4	**Verification of Remediation or Closure** • **No Action Needed**: If the data evaluation completed under Sections 2 and 3 demonstrated that there are no exceedances of cleanup criteria, no remedial action is required for this pathway and consequently no additional sampling or data analysis is required under Section 4. • **Excavation**: Numbers and locations of samples collected for verifying remediation of soil can be selected in accordance with either the tabbed section titled, "Sampling Strategies" (Sections 1.3 or 2.3 as appropriate based on size of excavation), or a DEQ-approved sampling plan when a person is seeking DEQ approval of the response activity. Analytical results from verification sampling must be compared to Part 201 criteria on a point-by-point basis* unless a minimum of nine *RANDOMLY* located samples are available within the *EXPOSURE UNIT(S)* or *EMISSION SOURCE AREA*, whichever is smaller. If a statistical analysis is used, analytical results from verification sampling must be compared to Part 201 criteria as described in Sections 2 and 3.

	Section 4: (Continued)	• **In situ/Ex situ Treatment**: Plans for verifying remediation or closure must be made on a case-by-case basis and must demonstrate how treatment is effective in meeting cleanup criteria. These plans may or may not depend on statistical analysis of data as allowed in Sections 2 and 3. • **Cover/Containment**: Generally soil sampling will not be used to verify Limited or Site-specific remediation or closure that relies on a cover or containment. Instead, verification of remediation will involve verifying the integrity of the cover or containment structure on an ongoing basis. Verification of remediation in areas outside the cover/containment structure will be done using the options above.
Additional Information:		Criteria Application Guidesheets 23, 24 and 25; "Part 201 Generic Soil Inhalation Criteria for Ambient Air: Technical Support Document".
Recommended Statistical Methods for Comparison to Criteria:		Compare *FACILITY* data to criteria using a 95% upper confidence limit (UCL) for the mean concentration (see Chapter 3 of the tabbed section titled, "Statistical Methods"). Other statistical methods may be acceptable on a case-by-case basis.

*Professional judgment is required to interpret the significance of exceedances that are very close to criteria, or that may be associated with insignificant quantities of hazardous substances.

***SOURCE SIZE MODIFIERS* for Ambient Air Soil Inhalation Criteria**

Modifiers		
Source Size (ft^2 or acres)	Q/C (g/m^2-s per kg/m^3)	Modifier
400 ft^2	261.26	3.17
1000 ft^2	180.76	2.2
2000 ft^2	144.91	1.76
1/4 acre	94.56	1.15
1/2 acre	82.33	1
1 acre	71.74	0.87
2 acre	63.51	0.77
5 acre	54.62	0.66
10 acre	49.13	0.6
32 acre	41.55	0.5
100 acre	35.66	0.43

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR **SOIL** DATA	Statistical Guidesheet 26

GENERIC COMMERCIAL II, III, IV AND INDUSTRIAL PARTICULATE SOIL INHALATION CRITERIA (PSIC) FOR AMBIENT AIR

May assist in evaluation of condition(s):	7
Applicability of Statistics	**YES**

Statistics are applicable for evaluating this exposure pathway. Use of statistics is practical when there are adequate data sets available in the *EXPOSURE UNITS* or *EMISSION SOURCE AREAS*, as appropriate to the *FACILITY*.

Key Considerations:

Section 1

Facility Determination

- Not applicable.

Section 2

Selection of Data For Statistical Analysis

- Samples collected for the purpose of characterizing a *FACILITY* are typically biased, based on factors such as historical information, previous sampling, disposal practices, visual impacts, and aerial photos. Once the nature and extent of contamination has been defined, it is necessary to identify and/or obtain data that will allow for appropriate comparison to criteria. There are two primary considerations in determining if data sets are adequate. First, data sets must be obtained from locations that are consistent with the exposure assumptions for the relevant land use scenario. Second, if statistics are used, data sets must contain a sufficient number of *RANDOMLY* located sample results to allow for proper statistical analysis and development of *REPRESENTATIVE CONCENTRATIONS*. Therefore, additional sampling to develop *REPRESENTATIVE CONCENTRATIONS* will often be required after the nature and extent of contamination have been defined. Some characterization data may be used in the development of a *REPRESENTATIVE CONCENTRATION* as described in Section 2.4.2 of the tabbed section titled, "Sampling Strategies."

- A statistical analysis of soil data should be completed only if the nature and extent of contamination, including any *HOT SPOTS*, has been adequately defined.

- It is not appropriate to combine samples from *HOT SPOT* areas with samples from other areas of a property for statistical analysis. This is necessary to avoid averaging or diluting the samples that represent *HOT SPOTS*. *HOT SPOTS* must be addressed separately. See Section 2.2.1.1 of the tabbed section titled, "Sampling Strategies."

★ A *SOURCE SIZE MODIFIER* must be selected for *EMISSION SOURCE SIZES* that are different than the assumed 1/2 acre *EMISSION SOURCE SIZE*. The *SOURCE SIZE MODIFIER* must correspond to an *EMISSION SOURCE SIZE* that is at least as large as the *EMISSION SOURCE SIZE* of the *FACILITY*. For example, if the *EMISSION SOURCE SIZE* at a *FACILITY* is at least eight acres, the generic soil inhalation criteria for a 1/2 acre *EMISSION SOURCE SIZE* is multiplied by the *SOURCE SIZE MODIFIER* for 10 acres to provide generic criteria for a 10 acre *FACILITY*. *SOURCE SIZE MODIFIERS* to adjust generic criteria for *EMISSION SOURCE SIZES* other than a 1/2 acre are provided in a table at the end of this guidesheet.

Section 3

Risk Analysis – Comparison to Criteria

★ Criteria for this pathway depend on the *EMISSION SOURCE SIZE*, which must be estimated in both the horizontal and vertical dimension. Criteria shown in the cleanup criteria tables are based on a 1/2 acre *EMISSION SOURCE SIZE*. *SOURCE SIZE MODIFIERS* to adjust generic criteria for *EMISSION SOURCE SIZES* other than a 1/2 acre are provided in a table at the end of this guidesheet. For convenience, this table has been updated to include 1/4 acre and two acre *EMISSION SOURCE SIZES* for use at residential/commercial I and commercial II, III, IV and industrial land uses, respectively.

Soil contamination for the PSIC pathway may occur in two general patterns that will affect the *EMISSION SOURCE SIZE* used to adjust the criteria for comparison to the *FACILITY* data:

★ **Properties or *FACILITIES* with a single *EMISSION SOURCE AREA***

If hazardous substances are detected in only a limited area within a two acre *EXPOSURE UNIT* and are not detected in other areas of the *EXPOSURE UNIT*, the *EMISSION SOURCE AREA* is equal to only the horizontal extent of the area with detectable concentrations. Only data within the *EMISSION SOURCE AREA* may be included in a statistical analysis.

For an *EMISSION SOURCE AREA* that is larger than two acres (i.e., *EXPOSURE UNIT*), soil concentrations within each two acre *EXPOSURE UNIT* must meet the PSIC adjusted for the *EMISSION SOURCE SIZE*.

★ **Properties with multiple *EMISSION SOURCE AREAS***

Properties larger than two acres may contain several small *EMISSION SOURCE AREAS*. Where hazardous substances are not detected in the areas of the property between *EMISSION SOURCE AREAS*, the final *EMISSION SOURCE SIZE* is the sum of the horizontal extent of all individual *EMISSION SOURCE AREAS*. Soil concentrations within each *EMISSION SOURCE AREA* are compared to the generic criteria adjusted for the summed area of the individual *EMISSION SOURCE AREA* sizes.

★ Statistical analysis is possible for either the *EXPOSURE UNIT* or the *EMISSION SOURCE AREA* provided that sufficient data are available as described in Section 2.

★ Nine *RANDOMLY* located samples per *EXPOSURE UNIT* or *EMISSION SOURCE AREA*, whichever is smaller, should generally be used to conduct the statistical analysis. The actual number of samples to be collected may vary based on size of the *EMISSION SOURCE AREA*. Data collected for other purposes (as for identification of nature and extent) may be used where *RANDOM* sample locations fall on or reasonably close to existing sample locations and where data will be consistent in terms of sampling and analytical methods.

- Statistical analyses must include an evaluation of the underlying statistical distribution of the data (i.e., normal, lognormal, or neither) and the level of censoring (i.e., proportion of the data below the detection limit). See the tabbed section titled, Statistical Methods." This evaluation must be completed for each hazardous substance. Additionally, the statistical methods used to compare *FACILITY* data to criteria must be selected based on statistical distribution and level of censoring.

	Section 3: (Continued)	★ Compliance with infinite generic PSIC must be demonstrated for the entire vertical soil column since hazardous substances in subsurface soil may contribute to emissions if moved to the surface in the future. • Statistical analysis of *FACILITY* data is not allowed for hazardous substances that have criteria based on acute toxicological effects and/or physical hazards. • If *BACKGROUND* concentrations in soil are greater than criteria, soil data may be compared to *BACKGROUND* instead. Statistical methods for determining *BACKGROUND* concentrations will vary depending on which type of *BACKGROUND* is being considered. See Statistical Guidesheet 10 and Chapter 4 of the tabbed section titled, "Statistical Methods."
	Section 4	**Verification of Remediation or Closure** • **No Action Needed**: If the data evaluation completed under Sections 2 and 3 demonstrated that there are no exceedances of cleanup criteria, no remedial action is required for this pathway and consequently no additional sampling or data analysis is required under Section 4. • **Excavation**: Numbers and locations of samples collected for verifying remediation of soil can be selected in accordance with either the tabbed section titled, "Sampling Strategies" (Sections 1.3 or 2.3 as appropriate based on size of excavation), or a DEQ-approved sampling plan when a person is seeking DEQ approval of the response activity. Analytical results from verification sampling must be compared to Part 201 criteria on a point-by-point basis* unless a minimum of nine *RANDOMLY* located samples are available within the *EXPOSURE UNIT(S)* or *EMISSION SOURCE AREA*, whichever is smaller. If a statistical analysis is used, analytical results from verification sampling must be compared to Part 201 criteria as described in Sections 2 and 3. • **In situ/Ex situ Treatment**: Plans for verifying remediation or closure must be made on a case-by-case basis and must demonstrate how treatment is effective in meeting cleanup criteria. These plans may or may not depend on statistical analysis of data as allowed in Sections 2 and 3. • **Cover/Containment**: Generally soil sampling will not be used to verify Limited or Site-specific remediation or closure that relies on a cover or containment. Instead, verification of remediation will involve verifying the integrity of the cover or containment structure on an ongoing basis. Verification of remediation in areas outside the cover/containment structure will be done using the options above.

Additional Information:	Criteria Application Guidesheet 22; "Part 201 Generic Soil Inhalation Criteria for Ambient Air: Technical Support Document"
Recommended Statistical Methods for Comparison to Criteria:	Compare *FACILITY* data to criteria using a 95% upper confidence limit (UCL) for the mean concentration (see Chapter 3 of the tabbed section titled, "Statistical Methods"). Other statistical methods may be acceptable on a case-by-case basis.

*Professional judgment is required to interpret the significance of exceedances that are very close to criteria, or that may be associated with insignificant quantities of hazardous substances.

SOURCE SIZE MODIFIERS for Ambient Air Soil Inhalation Criteria

Modifiers		
Source Size (ft^2 or acres)	Q/C (g/m^2-s per kg/m^3)	Modifier
400 ft^2	261.26	3.17
1000 ft^2	180.76	2.2
2000 ft^2	144.91	1.76
1/4 acre	94.56	1.15
1/2 acre	82.33	1
1 acre	71.74	0.87
2 acre	63.51	0.77
5 acre	54.62	0.66
10 acre	49.13	0.6
32 acre	41.55	0.5
100 acre	35.66	0.43

PART 201 STATISTICAL EVALUATION GUIDESHEET FOR SOIL DATA	Statistical Guidesheets 27, 28 and 29
GENERIC INDUSTRIAL AND COMMERCIAL II, III, IV DIRECT CONTACT CRITERIA (DCC)	
May assist in evaluation of condition(s):	6
Applicability of Statistics	**YES**
Statistics are applicable for evaluating this exposure pathway. Use of statistics is practical when there are adequate data sets available for the *EXPOSURE UNITS*.	

Key Considerations:	**Section 1**	**Facility Determination**
		• Not applicable.
	Section 2	**Selection of Data For Statistical Analysis**
		• Samples collected for the purpose of characterizing a *FACILITY* are typically biased, based on factors such as historical information, previous sampling, disposal practices, visual impacts, and aerial photos. Once the nature and extent of contamination has been defined, it is necessary to identify and/or obtain data that will allow for appropriate comparison to criteria. There are two primary considerations in determining if data sets are adequate. First, data sets must be obtained from locations that are consistent with the exposure assumptions for the relevant land use scenario. Second, if statistics are used, data sets must contain a sufficient number of *RANDOMLY* located sample results to allow for proper statistical analysis and development of *REPRESENTATIVE CONCENTRATIONS*. Therefore, additional sampling to develop *REPRESENTATIVE CONCENTRATIONS* will often be required after the nature and extent of contamination have been defined. Some characterization data may be used in the development of a *REPRESENTATIVE CONCENTRATION* as described in Section 2.4.2 of the tabbed section titled, "Sampling Strategies."
		• A statistical analysis of soil data should be completed only if the nature and extent of contamination, including any *HOT SPOTS*, has been adequately defined.
		• It is not appropriate to combine samples from *HOT SPOT* areas with samples from other areas of a property for statistical analysis. This is necessary to avoid averaging or diluting the samples that represent *HOT SPOTS*. *HOT SPOTS* must be addressed separately. See Section 2.2.1.1 of the tabbed section titled, "Sampling Strategies."
		★ Generally only soil data from a two acre *EXPOSURE UNIT* may be used in a statistical calculation for remedial compliance unless the property is smaller than 2 acres and the *FACILITY* is confined to the property. In that case, the *EXPOSURE UNIT* size will be same as the property size.
		★ Soil data from an *EXPOSURE UNIT* that reflects current human activity patterns may be used in a statistical calculation for Due Care compliance.

	Section 2: (Continued)	★ Compliance with these criteria must be demonstrated separately for surface and subsurface soils unless there is little variability between surface and subsurface data. Surface soils are typically defined as the top six inches of the soil column. However, if contamination is predominantly located at the immediate surface (such as through air deposition of hazardous substances), surface soil samples should represent the immediate surface (e.g., top one inch). ★ Subsurface soils should be evaluated in the same manner as surface soils; however, larger *EXPOSURE UNITS* and/or fewer samples may be acceptable if characterization of the property indicates that hazardous substances are predominantly at the surface. ★ *EXPOSURE UNITS* larger than the standard two acres may be used for both Due Care and Remedial Compliance if it has been demonstrated that there is little variability among concentrations of hazardous substances in the *EXPOSURE UNIT* to be evaluated.
	Section 3	**Risk Analysis – Comparison to Criteria** ★ For remedial compliance, the *FACILITY* must generally be divided into two acre *EXPOSURE UNITS* for comparison to these criteria. *EXPOSURE UNIT* size can be different for surface and subsurface soil. Areas classified as *HOT SPOTS* must be evaluated separately. A minimum of nine *RANDOMLY* located samples per *EXPOSURE UNIT* (considering surface soil and subsurface soil separately) are required to conduct the statistical analysis. This number is based on statistical considerations only. Additional samples may be necessary to adequately characterize and represent spatial variability in the *EXPOSURE UNIT* depending on such factors as soil type, and size of the *EXPOSURE UNIT*. ★ *EXPOSURE UNITS* for Due Care should be based on exposures currently occurring and reasonably likely to occur based on human activity patterns at the *FACILITY*. If activities are concentrated in an area smaller than the standard *EXPOSURE UNIT*, *EXPOSURE UNITS* smaller than two acres should be used. • Statistical analyses must include an evaluation of the underlying statistical distribution of the data (i.e., normal, lognormal, or neither) and the level of censoring (i.e., proportion of the data below the detection limit). See the tabbed section titled, “Statistical Methods.” This evaluation must be completed for each hazardous substance. The statistical methods used to compare *FACILITY* data to criteria must be selected based on statistical distribution and level of censoring. • If *BACKGROUND* concentrations in soil are greater than criteria, soil data may be compared to *BACKGROUND* instead. Statistical methods for determining *BACKGROUND* concentrations will vary depending on which type of *BACKGROUND* is being considered. See Statistical Guidesheet 10 and Chapter 4 of the tabbed section titled, “Statistical Methods.” • Statistical analysis of *FACILITY* data is not allowed for hazardous substances present above Csat screening levels without further evaluation of risk and the extent of the area exceeding Csat. • Statistical analysis of *FACILITY* data is not allowed for hazardous substances that have criteria based on acute toxicological effects and/or physical hazards.

	Section 4	**Verification of Remediation or Closure**
		• **No Action Needed**: If the data evaluation completed under Sections 2 and 3 demonstrated that there are no exceedances of cleanup criteria, no remedial action is required for this pathway and consequently no additional sampling or data analysis is required under Section 4. • **Excavation**: Numbers and locations of samples collected for verifying remediation of soil can be selected in accordance with either the tabbed section titled, "Sampling Strategies" (Sections 1.3 or 2.3 as appropriate based on size of excavation), or a DEQ-approved sampling plan when a person is seeking DEQ approval of the response activity. Analytical results from verification sampling must be compared to Part 201 criteria on a point-by-point basis* unless a minimum of nine *RANDOMLY* located samples are available within the *EXPOSURE UNIT(S).* If a statistical analysis is used analytical results from verification sampling must be compared to Part 201 criteria as described in Sections 2 and 3. • **In situ/Ex situ Treatment**: Plans for verifying remediation or closure must be made on a case-by-case basis and must demonstrate how treatment is effective in meeting cleanup criteria. These plans may or may not depend on statistical analysis of data. • **Cover/Containment**: Generally soil sampling will not be used to verify Limited or Site-specific remediation or closure that relies on a cover or containment. Instead, verification of remediation will involve verifying the integrity of the cover or containment structure on an ongoing basis. Verification of remediation in areas outside the cover/containment structure will be done using the options above. • If *BACKGROUND* concentrations in soil are greater than criteria, soil data may be compared to *BACKGROUND* instead. Statistical methods for determining *BACKGROUND* concentrations will vary depending on which type of *BACKGROUND* is being considered. See Statistical Guidesheet 10 and Chapter 4 of the tabbed section titled, "Statistical Methods."
Additional Information:		Criteria Application Guidesheets 27, 28 & 29
Recommended Statistical Methods for Comparison to Criteria:		Compare *FACILITY* data to criteria using a 95% upper confidence limit (UCL) for the mean concentration (see Chapter 3 of the tabbed section titled, "Statistical Methods"). Other statistical methods may be acceptable on case-by-case basis.

*Professional judgment is required to interpret the significance of exceedances that are very close to criteria, or that may be associated with insignificant quantities of hazardous substances.

USE OF STATISTICS IN ASSESSING "DUE CARE" COMPLIANCE

USE OF STATISTICS IN ASSESSING "DUE CARE" COMPLIANCE

Staff and *FACILITY* owner/operators may need to evaluate data to assess compliance with Section 7a ("Due Care") and the Part 10 rules. Generally, the applicability of statistics will be the same in the Due Care context for the other purposes described in the Statistical Guidesheets (e.g., verification of remediation). Therefore, if the Applicability of Statistics box on the Statistical Guidesheet for an exposure pathway or condition denotes YES, it is appropriate to use statistics in a Due Care evaluation, if the data are sufficient. If Applicability is denoted as GNP, it is important to determine whether an adequate data set is available for evaluation of Due Care. The minimum data requirements are the same for Due Care as for other applications (e.g., number of samples per *EXPOSURE UNIT*, need for data to reflect *REPRESENTATIVE CONCENTRATIONS*).

The goal of Section 7a(1)(b) is protection of public health and safety. Compliance with this Section requires that response activity be undertaken to mitigate unacceptable exposure to hazardous substances and fire and explosion hazards. Recall that under Rule 1003(4)(a)(i), Due Care compliance is evaluated for the exposure pathways that are complete or likely to be complete in light of the intended use of the property. Not all exposure pathways and conditions to consider are relevant to Due Care. For example, the drinking water ingestion pathway is not relevant when drinking water is provided from a municipal supply that is unaffected by contamination from the *FACILITY*. The GSI pathway is generally not relevant for Due Care. Also, the intended use at a *FACILITY* may limit exposure to contaminated media, such that only a portion of the contaminated media needs to evaluated. For example, if planned activities at a *FACILITY* would not result in excavation below the top 12 inches of soil, the direct contact pathway would not need to be evaluated for soil more than 12 inches deep.

The following table summarizes how Due Care compliance may vary from evaluation in the remedial action context.

Statistical Guidesheet	Pathway	How Due Care and Use of Statistics to Evaluate Compliance May Be Different than Remedial Compliance
A	Abandoned substances not yet dispersed & free phase liquids	Source control may contribute to preventing or mitigating unacceptable exposures. Statistics generally not practical in defining or assessing effectiveness of source control activities because this is typically a qualitative evaluation.
B	Polluted soil runoff to surface water	Generally not relevant to Due Care compliance.
C	Aquatic flora/fauna/food chain hazards/ aesthetics	Generally not relevant to Due Care compliance.
D	Acute toxic impacts/physical hazards	This condition may need to be addressed as part of Due Care compliance to mitigate unacceptable exposures or fire and explosion hazards. Statistics generally not practical for evaluating compliance because of the acute nature of the hazards.
E	Terrestrial flora/fauna/food chain hazards/ aesthetics	Generally not relevant to Due Care compliance.

F	Asbestos	Asbestos may need to be addressed to mitigate unacceptable exposure. Relevant to Due Care in areas and through exposure pathways where asbestos exposures may occur. Use of statistics in those areas would be the same as described in the Statistical Guidesheet for the relevant exposure pathways.
1	Groundwater: Drinking water usage (Res)	Relevant to Due Care compliance if groundwater is being used for drinking water. Statistics not applicable for evaluating Due Care compliance.
2	Groundwater: Drinking water usage (C/I)	Relevant to Due Care compliance if groundwater is being used for drinking water. Statistics not applicable for evaluating Due Care compliance.
3	Groundwater: Hazards to surface waters (All)	Generally not relevant to Due Care compliance except for conditions in venting groundwater that could result in unacceptable human exposure at GSI (e.g., very high or low pH) or if there is a drinking water intake close to point of venting.
4	Groundwater: Indoor air hazards (chronic /systemic) (Res)	Relevant to Due Care compliance if volatile contaminants are present in groundwater under existing or planned structures. Use of statistics is the same as described in the Statistical Guidesheet. Due Care compliance can be based on size of existing or planned structure, and can take into account building characteristics (e.g., ventilation rates) that are different from generic assumptions. Data needs for *REPRESENTATIVE CONCENTRATION* and minimum number of data points per building footprint/*EXPOSURE UNIT* are the same as for remedial compliance. *HOT SPOTS* must be evaluated separately to determine if they represent an unacceptable risk.
5	Groundwater: Indoor air hazards (chronic /systemic) (C/I)	Relevant to Due Care compliance if volatile contaminants are present in groundwater under existing or planned structures. Use of statistics is the same as described in the Statistical Guidesheet. Due Care compliance can be based on size of existing or planned structure, and can take into account building characteristics (e.g., ventilation rates) that are different from generic assumptions. Data needs for *REPRESENTATIVE CONCENTRATION* and minimum number of data points per building footprint/*EXPOSURE UNIT* are the same as for remedial compliance. *HOT SPOTS* must be evaluated separately to determine if they represent an unacceptable risk.
6	Groundwater: Dermal exposures such as by utility workers (All)	Relevant to Due Care compliance if contact with groundwater is reasonably likely to occur given intended use of property. Area evaluated can be limited to location of likely groundwater contact, in light of existing features. Use of statistics is the same as described in the Statistical Guidesheet. Data needs for *REPRESENTATIVE CONCENTRATION* and minimum number of data points per building footprint/*EXPOSURE UNIT* are the same as for remedial compliance. *HOT SPOTS* must be evaluated separately to determine if they represent an unacceptable risk.

7	Groundwater: Water Solubility (All)	Relevant to Due Care if a generic cleanup criterion for an exposure pathway or condition that is relevant defaults to water solubility. Use of statistics is the same as described in the Statistical Guidesheet for the relevant pathway.
8	Groundwater: Flammability / Explosivity (All)	This condition may need to be addressed as part of Due Care compliance to mitigate unacceptable fire and explosion hazards. Statistics generally not practical for evaluating compliance because of the acute nature of the hazards.
9	Groundwater: Acute Inhalation Risks (All)	This condition may need to be addressed as part of Due Care compliance to mitigate unacceptable exposures. Statistics generally not practical for evaluating compliance because of the acute nature of the hazards.
10	Background (All)	*BACKGROUND* may be relevant in evaluating Due Care compliance if an applicable cleanup criterion defaults to *BACKGROUND*. Use of statistics is the same as described in the Statistical Guidesheet for the relevant exposure pathway.
11	Soil: Injury to drinking water use of aquifer (Res)	Generally not relevant to Due Care compliance.
12	Soil: Causes groundwater to be hazardous to surface water (All)	Generally not relevant to Due Care compliance.
13	Soil: Risk from contact (utility work) with groundwater (All)	Generally not relevant to Due Care compliance.
14	Soil: Indoor air inhalation hazards (Res)	Relevant to Due Care compliance if volatile contaminants are present in soil under existing or planned structures. Use of statistics is the same as described in the Statistical Guidesheet. Due Care compliance can be based on size of an existing or planned structure, and can take into account building characteristics (e.g., ventilation rates) that are different from generic assumptions. Data needs for *REPRESENTATIVE CONCENTRATION* and minimum number of data points per building footprint/*EXPOSURE UNIT* are the same as for remedial compliance. *HOT SPOTS* must be evaluated separately to determine if they represent an unacceptable risk.
15, 16, 17	Soil: Ambient air inhalation hazards (Volatile) (All)	Relevant to Due Care compliance if volatile contaminants are present in soil. Use of statistics is the same as described in the Statistical Guidesheet. *EXPOSURE UNIT* size may be modified from generic size if appropriate to the activity patterns on the property. *EMISSION SOURCE AREA* the same as for remedial compliance. Data needs for *REPRESENTATIVE CONCENTRATION* and minimum number of data points per *EXPOSURE UNIT* or *EMISSION SOURCE AREA* are the same as for remedial compliance. *HOT SPOTS* must be evaluated separately to determine if they represent an unacceptable risk.

18	Soil: Ambient air inhalation hazards (Particulate) (C/I)	Relevant to Due Care compliance. Use of statistics is the same as described in the Statistical Guidesheet. Depth of soil evaluated can be limited if activity at property will not result in disturbance of existing surface soils. Data needs for *REPRESENTATIVE CONCENTRATION* and minimum number of data points per *EXPOSURE UNIT* or *EMISSION SOURCE AREA* are the same as for remedial compliance. *HOT SPOTS* must be evaluated separately to determine if they represent an unacceptable risk.
19	Hazards due to direct contact (Res)	Relevant to Due Care compliance. Use of statistics is the same as described in the Statistical Guidesheet. Depth of soil evaluated can be limited if activity at property will not result in disturbance of existing surface soils. *EXPOSURE UNIT* size can be based on existing and planned activity patterns, rather than standard size. Data needs for *REPRESENTATIVE CONCENTRATION* and minimum number of data points per *EXPOSURE UNIT* are the same as for remedial compliance. *HOT SPOTS* must be evaluated separately to determine if they represent an unacceptable risk.
20	Soil Saturation	Relevant to Due Care if a generic cleanup criterion for an exposure pathway or condition that is relevant defaults to Csat. Use of statistics is the same as described in the Statistical Guidesheet. Data needs for *REPRESENTATIVE CONCENTRATION* and minimum number of data points per building footprint/*EXPOSURE UNIT* are the same as for remedial compliance. *HOT SPOTS* must be evaluated separately to determine if they represent an unacceptable risk.
21	Soil: Injury to drinking water use of aquifer (C/I)	Generally not relevant to Due Care compliance.
22	Soil: Indoor air inhalation hazards (C/I)	Relevant to Due Care compliance if volatile contaminants are present in soil under existing or planned structures. Use of statistics is the same as described in the Statistical Guidesheet. Due Care compliance can be based on size of existing or planned structure, and can take into account building characteristics (e.g., ventilation rates) that are different from generic assumptions. Data needs for *REPRESENTATIVE CONCENTRATION* and minimum number of data points per building footprint/*EXPOSURE UNIT* are the same as for remedial compliance. *HOT SPOTS* must be evaluated separately to determine if they represent an unacceptable risk.

23, 24, 25	Soil: Ambient air inhalation hazards (Volatile) (C/I)	Relevant to Due Care compliance if volatile contaminants are present in soil. Use of statistics is the same as described in the Statistical Guidesheet. *EXPOSURE UNIT* size may be modified from generic size if appropriate to the activity patterns on the property. *EMISSION SOURCE AREA* the same as for remedial compliance. Data needs for *REPRESENTATIVE CONCENTRATION* and minimum number of data points per *EXPOSURE UNIT* or *EMISSION SOURCE AREA* are the same as for remedial compliance. *HOT SPOTS* must be evaluated separately to determine if they represent an unacceptable risk.
26	Soil: Ambient air inhalation hazards (Particulate) (C/I)	Relevant to Due Care compliance. Use of statistics is the same as described in the Statistical Guidesheet. Depth of soil evaluated can be limited if activity at property will not result in disturbance of existing surface soils. Data needs for *REPRESENTATIVE CONCENTRATION* and minimum number of data points per *EXPOSURE UNIT* or *EMISSION SOURCE AREA* are the same as for remedial compliance. *HOT SPOTS* must be evaluated separately to determine if they represent an unacceptable risk.
27, 28, 29	Soil: Hazards due to direct contact (C/I)	Relevant to Due Care compliance. Use of statistics is the same as described in the Statistical Guidesheet. Depth of soil evaluated can be limited if activity at property will not result in disturbance of existing surface soils. *EXPOSURE UNIT* size can be based on existing and planned activity patterns, rather than standard size. Data needs for *REPRESENTATIVE CONCENTRATION* and minimum number of data points per *EXPOSURE UNIT* are the same as for remedial compliance. *HOT SPOTS* must be evaluated separately to determine if they represent an unacceptable risk.

Key: Res – Residential and Commercial I Land Use Categories
C/I – Commercial II, III, IV and Industrial Land Use Categories
All – All Land Use Categories

STATISTICAL METHODS FOR COMPARING FACILITY DATA TO PART 201 CRITERIA

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INTRODUCTION

"[Statistics are] the only tools by which an opening can be cut through the formidable thicket of difficulties that bars the path of those who pursue the science of man."
-Sir Francis Galton

"By a small sample, we may judge of the whole piece."
-Miguel de Cervantes from Don Quixote

“Data! Data! Data! I can't make bricks without clay!”
-Sherlock Holmes

Use of this Document

Statistics provide important tools for describing and understanding the characteristics of data. Without statistics, quantifying the properties of a data set and drawing conclusions about the population from which the data were sampled is impossible. The following document has grown out of a need for a simple, yet comprehensive, approach to analyzing environmental data sets. It was composed with the intent of providing a clear, easy-to-use summary of the statistical methods available for various uses and how to implement these methods. Rather than providing a cookbook of statistical techniques where you just look up what you need and then “plug-and-chug” with the appropriate numbers and formulas, this document was meant to be used as a whole. Analyzing any data set is a process with several steps, not just one. This document is intended to provide a simple description and rationale behind those steps.

Common uses of statistics in Michigan’s Part 201 program include:

1) comparison of *FACILITY* data to the risk-based Part 201 criteria, and
2) comparison of *FACILITY* data to *FACILITY-SPECIFIC BACKGROUND*, *STATEWIDE DEFAULT BACKGROUND*, or *REGIONAL BACKGROUND* concentrations.

Statistical methods needed for these tasks are presented in the order that they are typically completed in conducting these statistical analyses. Chapter 1 provides recommended methods for evaluating the statistical distribution of a data set. Data sets will typically include either *FACILITY* data within a specified area (e.g., an *EXPOSURE UNIT*) or *FACILITY-SPECIFIC BACKGROUND* data. Chapter 2 describes methods for evaluating and recommendations for handling statistical outliers. Chapter 3 presents acceptable methods for comparing *FACILITY* data to Part 201 criteria. Chapter 4 provides statistical methods for comparing *FACILITY* data to the various types of *BACKGROUND* data that may be used. Recommendations for handling data below the detection limit or nondetects (generally substituting 1/2 of the detection limit) are provided throughout. Handling nondetects, including alternative methods, is discussed in more detail in Chapter 5.

For each method described herein, the following are provided: background information, assumptions underlying the method and their verification, a description including procedures for implementing the method, and an example analysis illustrating the steps that are required.

The approaches described in this document include use of summary statistics, graphical techniques, and formal statistical tests. Summary statistics help the user to understand characteristics of the data. Graphical techniques allow the user to view the data and greatly enhance the user’s understanding of the data. Formal statistical tests provide an objective

framework for making decisions about the data. Used together, these methods provide a strong framework for making decisions about and understanding the data.

Use of professional judgment is also an integral part of any statistical analysis. Statistics is a tool that may be used to help make decisions about Part 201 *FACILITIES*. However, used incorrectly, the decisions that are made may not reflect reality. Consequently, professional judgment must be used throughout in evaluating the data, selecting the appropriate statistical test, and drawing conclusions about a *FACILITY* based on a statistical analysis.

The statistical methods described herein are generally acceptable without approval when conducted within the framework described throughout the S^{3}TM. Alternative statistical methods are acceptable on a case-by-case basis. If departmental approval for a response action is being sought, alternative methods must be *PROPOSED* for approval by the DEQ statistician. The terms "*PROPOSE,*" "*PROPOSED,*" and "*PROPOSAL*" are used throughout the S^{3}TM to describe the process through which a statistical analysis of data is submitted to and reviewed by the department for approval, when necessary. Self-implemented response activities using statistics to support determinations must be documented in a manner that fully and clearly addresses the three questions outlined in the tabbed section titled, "Introduction."

Use of Computers in Statistical Analyses

Use of computer programs such as statistical software or spreadsheets is recommended to the extent possible when conducting statistical analyses. Calculation of statistical quantities by hand can not only be tedious, but is prone to error. Although formulas for calculating these quantities are provided herein, use of statistical software and/or spreadsheets is described and recommended throughout.



To highlight when a computer can be used to assist in an analysis, a computer icon is shown wherever computer "short-cuts" are provided. Microsoft Excel formulas are provided, where applicable, in the form:

=function(data range)

where "function" refers to the operation applied to the data (e.g., "average" or "stdev") and "data range" refers to the range over which the data to be evaluated appear on the spread sheet (e.g., A1:A20).

Occasionally a statistical method is a bit too complicated to conduct using a spreadsheet and a more powerful statistical software package is required. The DEQ has developed a customized statistical software package called "Statistical Interface for Part 201 Evaluations." This package was developed using a statistical software package called "S-PLUS StatServer 6" (StatServer) and many of the specialized statistical functions necessary for environmental data analysis provided by EnvironmentalStats for S-PLUS. This software is accessible to all staff in the department as well as the public through the Internet.

Interpretation of Statistical Results and Use of Professional Judgment



To aid understanding and comprehension, this document includes examples for each method presented. At the end of each example, interpretation of the results is discussed. The icon to the left is shown to highlight where information on interpretation of the statistical results can be found.

As stated above, use of professional judgment is an integral part of any statistical analysis and must be used when interpreting statistical results. The results of any statistical analysis should be carefully examined. This may be particularly important if the results of a statistical analysis do not conform with expectations. For example, if hazardous substance concentrations in an area of a property are clearly above criteria, yet a statistical analysis concludes that concentrations are below criteria, the test should be reevaluated. It is also possible that a statistical test will indicate that an area is above criteria when there are only one or two marginal exceedances of criteria. Several aspects of the analysis should be checked, including:

- Characterization – Was the property adequately characterized? (See the tabbed section titled, "Sampling Strategies.")

- Applicability of statistics – For exposure pathways/conditions in which use of statistics is "Generally Not Practical" (GNP), was it appropriate to conduct a statistical analysis of the data given the above? (See the appropriate Statistical Guidesheet.)

- Data set – Was the data set selected to represent a single population within an appropriate area (e.g., an *EXPOSURE UNIT*)? (See Sections 2 and 3 of the appropriate Statistical Guidesheet and the tabbed section titled, "Sampling Strategies.")

- Statistical test – Was the appropriate statistical test selected? Were the assumptions of the statistical test adequately evaluated? Were there any questions or uncertainties in whether the assumptions were met? Should an alternate statistical test be *PROPOSED*?

It is important that the above issues are addressed in any statistical analysis. If the entire S^3TM is followed through the course of an analysis, these issues will be addressed up front. However, unexpected or questionable conclusions may still be reached. It is possible that the original expectations about a data set or a *FACILITY* were incorrect and that the statistical analysis shed new insight on conditions at the *FACILITY*. However, the likelihood that a correct conclusion is drawn as well as a user's level of comfort with a statistical analysis can only be improved by scrutinizing statistical results.

CHAPTER 1: STATISTICAL DISTRIBUTIONS

Common uses of statistics in Michigan's Part 201 program include:

1) comparison of *FACILITY* data to Part 201 cleanup criteria, and
2) comparison of *FACILITY* data to *FACILITY-SPECIFIC BACKGROUND*, *STATEWIDE DEFAULT BACKGROUND*, or *REGIONAL BACKGROUND* concentrations.

Chapters 3 and 4 of Statistical Methods describe recommended statistical methods for these uses, respectively. However, before proceeding to these chapters, it is important to evaluate *FACILITY* data and, when available, *FACILITY-SPECIFIC BACKGROUND* data as described in Chapters 1 and 2 in order to select an appropriate statistical method for comparison.

1.1 IDENTIFICATION OF APPROPRIATE DATA SETS

Before utilizing statistics to compare *FACILITY* data to Part 201 criteria or *BACKGROUND* concentrations, it is important to first select the data set(s) you want to evaluate and the associated population(s). It is a relatively straightforward matter to enter numbers into formulas, but meaningful results and accurate conclusions are not likely unless careful consideration is given to the data being used in the analysis and the manner in which they were collected.

Proper identification of data sets for statistical analysis relies on adequate site characterization information. (See Sections 1.3 and 2.3 of the tabbed section titled, "Sampling Strategies.") Once a *FACILITY* has been adequately characterized, appropriate data sets must be selected as described in Parts 2 and 3 of the appropriate Statistical Guidesheets. Information on *HOT SPOTS* is also provided in Section 2.2.1.1 of the tabbed section titled, "Sampling Strategies." In addition, instructions for obtaining *RANDOM* samples is described in Section 2.4.2 of the tabbed section titled, "Sampling Strategies." This section also describes the importance of *RANDOM* sampling when comparing *FACILITY* data to Part 201 criteria, as well as recommendations on how to incorporate *FACILITY* characterization data into the data set for statistical analysis.

1.2 DISTRIBUTION TYPES

Before selecting between the various statistical methods provided in Chapters 3 and 4 for comparing *FACILITY* data to Part 201 risk-based criteria or *BACKGROUND* concentrations, respectively, it is important to understand the underlying assumptions for each method. Many statistical methods are based on an assumption that the data being evaluated come from a normal probability distribution. (The concepts of probability distributions and the normal distribution are described below.) If this assumption is not accurate, alternative methods may be required. Consequently, once an appropriate data set has been selected according to the considerations described in Section 1.1, the next step is to evaluate the data to determine its underlying statistical distribution.

In statistics, a probability distribution is mathematic rule or formula that gives the probability associated with obtaining various observations from a population. Values that have a high probability will be observed in *RANDOM* samples more frequently than values with low probability. Similarly, values with equal probability will show up in *RANDOM* samples with roughly the same frequency. As an example, for a fair coin toss there is a 50% chance of obtaining a "head" and a 50% chance of obtaining a "tail." This 50/50 chance of obtaining a head or a tail is an example of a simple probability distribution.

The most commonly known probability distribution is the normal distribution. The normal distribution can be illustrated by the familiar bell-shaped curve (Figure 1.1). The mean and variance determine the location and shape, respectively, of different normal curves. For example, Figure 1.2a illustrates the difference between two normal distributions with differing means, but the same variance. The shapes of these curves are the same, but the locations on the x-axis differ. Figure 1.2b shows two normal distributions with the same mean value, but differing variances. Although these curves are centered at the same location, the shapes of the curves are different. The curve with the larger variance is wider than the other curve, illustrating that there is a larger amount of variability in the distribution of the data. Many statistical methods are based on an assumption of normality (i.e., the data being evaluated come from a normal distribution). Alternate statistical methods may be needed if the data under evaluation are not normal.

The normal distribution can be used to describe positive-valued data, negative-valued data, or both. Because negative values are frequently not plausible for environmental data (e.g., negative concentrations), the normal distribution has some limitations in use.

Figure 1.1 Standard Normal Distribution

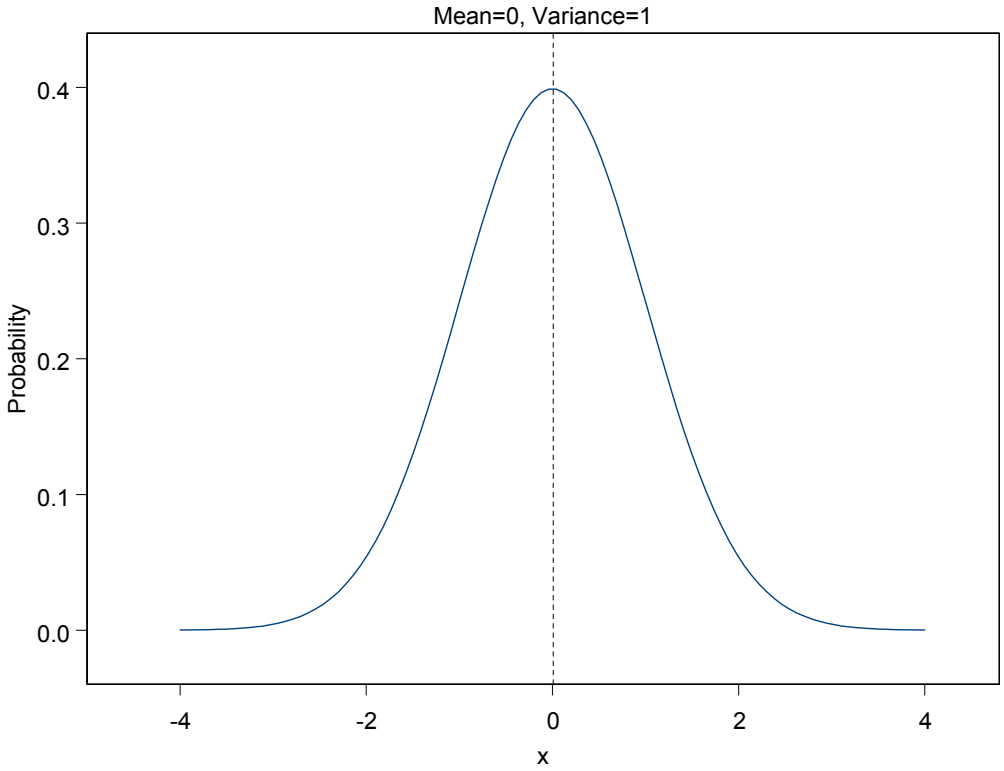


Figure 1.2a Two Normal Distributions (Different Means, Equal Variances)

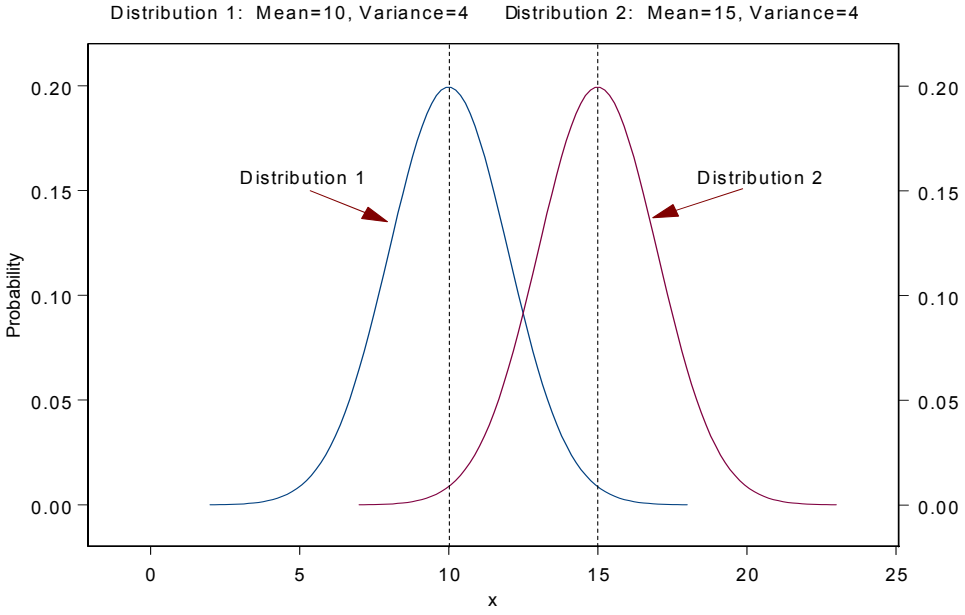
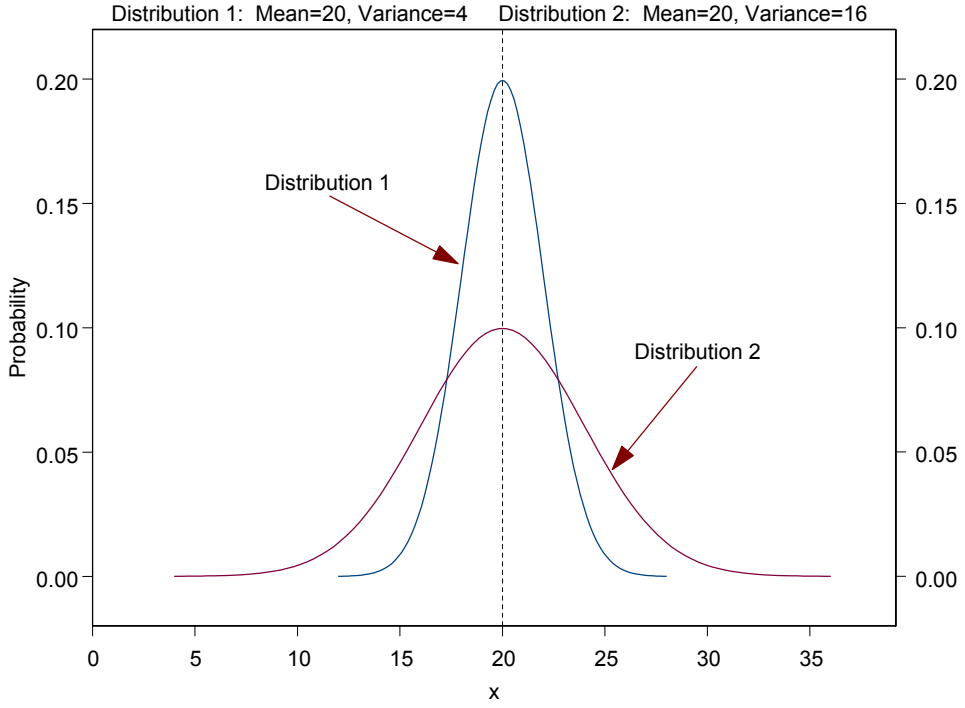
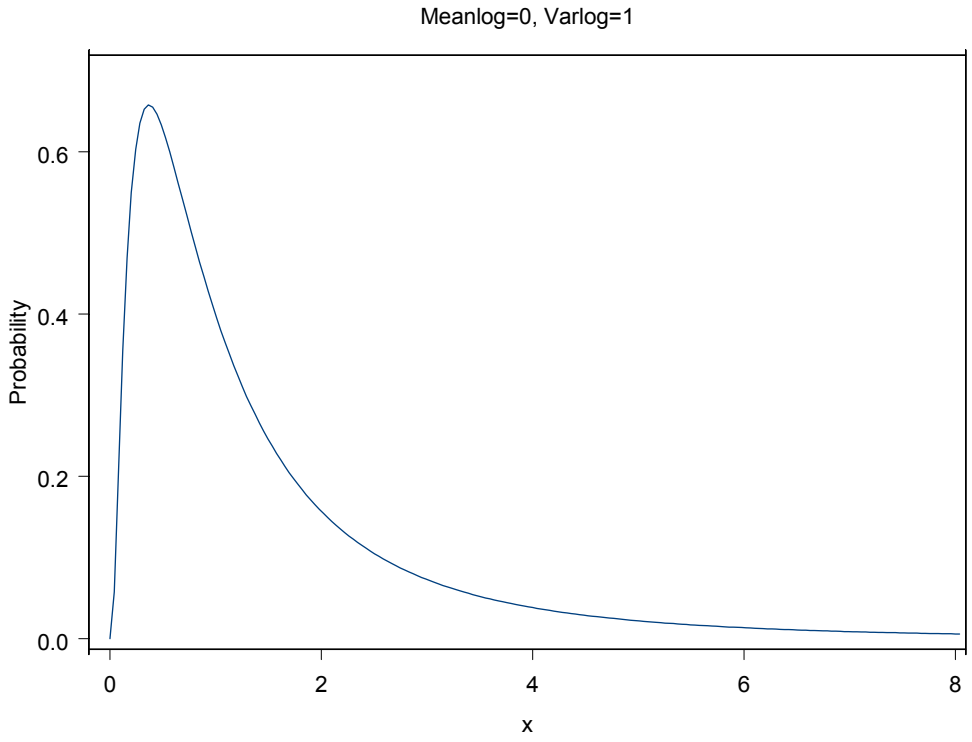


Figure 1.2b Two Normal Distributions (Equal Means, Different Variances)



Another common distribution used to model environmental data is the lognormal distribution (Figure 1.3). The lognormal distribution is characterized by a lower bound of zero and a right-skewed density function (i.e., the shape of the distribution is asymmetric with a long right tail). Because of the zero lower bound, the lognormal distribution can only be used to describe positive-valued data. These distributional characteristics often make the lognormal model a better candidate for describing environmental data sets. This idea is supported by Ott (1990) who demonstrates that there is a theoretical basis for the common occurrence of the lognormal distribution in environmental data.

Figure 1.3 Lognormal Distribution



As their names might suggest, there is a close relationship between the normal and lognormal distributions. Simply put, if a set of data $x_1, x_2, ..., x_n$ are lognormally distributed, then the set $y_1, y_2, ..., y_n$ representing the natural logs of the original observations (i.e., $y_i = \ln(x_i)$) will be normally distributed. In this case, log-transforming the original data set results in a normally-distributed data set.

Calculating the natural logs of the data is an example of a transformation of the original data set to achieve a normally-distributed data set. Transformations are used for changing the scale and range of data to obtain better statistical properties. Other methods for transforming data to normality are available (e.g., the Box-Cox family of transformations *PROPOSED* by Box and Cox (1964)); however, these methods are outside of the scope of this document. Transforming data to other scales often results in additional complexities when interpreting statistical results. Because of this and the common occurrence of the lognormal distribution in environmental data, the EPA (1992c) generally recommends testing for normality and lognormality only. Alternate methods for transforming data may be *PROPOSED* for review by the DEQ statistician.

Various statistical guidance documents suggest using a default assumption of normality or lognormality (i.e., test first for normality or lognormality; if the data pass a test for the default distribution, no further testing is recommended). **However, it is recommended here that all data be evaluated for *both* the normal and lognormal distributions. The results of these evaluations should be compared to determine which distribution provides a better fit to the data and, as a result, which methods are most appropriate.**

Experience has shown that some data sets do not conform to either distribution type. This may be due to many reasons, including:

- the presence of one or more outliers (see Chapter 2),
- the combination of data from multiple populations (e.g., *HOT SPOT* and non- *HOT SPOT* data) into a single data set, or
- the proportion of concentrations below the detection limit is too large (> 50%) to adequately evaluate the underlying distribution.

Appropriate selection of data sets as described in the Statistical Guidesheets should lessen problems associated with the first two points above. When the percent of concentrations below the detection limit is > 50%, it is generally not possible to evaluate the statistical distribution as described in Section 1.3. In some cases, alternate statistical methods are described for evaluating data sets with 50% or more of values below the detection limit. Consultation with a professional statistician is advised. In any case, alternate statistical methods may be *PROPOSED* for approval by the DEQ statistician.

1.3 METHODS FOR EVALUATING STATISTICAL DISTRIBUTIONS

Several methods are available for evaluating the statistical distribution of a data set. These methods include summary statistics, graphical techniques and formal tests. Most of these methods can be used to evaluate data for both normality and lognormality.

For each of these methods, it is recommended that a minimum of nine samples be used to evaluate for statistical distribution. A minimum of nine samples was selected in an effort to balance costs of sampling and analysis with statistical rigor. Tests for normality can be completed using as few as three samples (EPA 2000); however, the statistical power to conclude that the data are not normal (or lognormal) is low. Other sources recommend that sample sizes of 20 or more are required to attain reasonable power in tests of normality (e.g., EPA 1992a, EPA 1992c). Recognizing that this minimum number of samples must be collected from each *EXPOSURE UNIT* or area for which a statistical analysis is completed, the recommended minimum of samples was selected to represent the lower end of the range cited in literature. Because use of a relatively small sample size results in reduced power in tests of normality, a variety of techniques for evaluating distribution are recommended.

If it can be reasonably concluded that concentrations from multiple *EXPOSURE UNITS* or areas can be modeled by the same statistical distribution (e.g., due to placement of homogeneous fill materials over a large area), it may be appropriate to pool data from these areas when testing for distribution in order to increase sample size. If this approach is considered, a *PROPOSAL* should be submitted for review by the DEQ statistician. Consultation with a professional statistician is advised when developing this approach.

In some cases, it may be difficult to determine which distribution is most appropriate. **A final choice of statistical distribution should be made based on evaluation of the collective results of the different methods described below.**

A number of methods are provided in this section to evaluate data for a normal or lognormal distribution. These methods are summarized below:

Type of Method	Method	Section
Summary Statistic	Coefficient of Variation	1.3.1
Summary Statistic	Coefficient of Skewness	1.3.2
Graphical Technique	Probability Plots	1.3.3
Graphical Technique	Box Plots	1.3.4
Formal Test	Shapiro-Wilk Test ($n \leq 50$)	1.3.5
Formal Test	Shapiro-Francia Test ($n > 50$)	1.3.6
Formal Test	D'Agostino's Test ($n > 50$)	1.3.7

Summary statistics provide a simple way to evaluate the distribution of data. Summary statistics include descriptive values like the mean and standard deviation. These values are called summary statistics, or descriptive statistics, because they summarize the information contained in the data set and describe certain properties of the data set, such as central tendency and variability. The coefficient of variation and the coefficient of skewness are two more examples of summary statistics. The coefficient of variation measures the relative variability of the data set and provides a rough indication of the likelihood that the data are normal. The coefficient of skewness provides a measure of symmetry or asymmetry (i.e., skewness) of the data.

Graphical techniques provide a visual depiction of the data and are an excellent tool for inspecting data and their resemblance to a particular distribution. For example, a data set may fail a formal test of normality due to the presence of an outlier (i.e., without the outlier, the data would be normally distributed). This may not be apparent based on inspection of summary statistics or formal test results. Upon graphing the data, the cause for non-normality (an outlier, in this case) may be evident, allowing for possible modifications to the data (e.g., correction of an erroneous analytical result) and/or statistical approach. Note that identification and treatment of outliers is discussed in detail in Chapter 2. Because interpretation of graphical results may be somewhat subjective, decisions regarding statistical distribution should not be made using graphical methods alone.

Formal testing provides an objective framework for making decisions about the statistical distribution since a data set will either pass or fail a test for normality or lognormality. Subjectivity is largely absent when conducting a formal test and interpreting the result. Thus, formal tests provide the benefit of an objective framework for making decisions about data. However, as noted above, if a data set fails a formal test for normality or lognormality, the formal test results alone may not provide insight as to why a particular data set failed.

Used together, formal tests, graphical techniques, and summary statistics provide a strong framework for making decisions about and understanding the data. Consequently, a final choice of statistical distribution should be made based on evaluation of the collective results of the methods described below. **At a minimum, all statistical reports or *PROPOSALS* should include calculation of summary statistics, normal and lognormal probability plots, and**

the Shapiro-Wilk or Shapiro-Francia Tests for each contaminant in order to evaluate both normality and lognormality. Alternative methods for evaluating statistical distributions may be *PROPOSED* for review by the DEQ statistician.

1.3.1 Coefficient of Variation (CV)

The CV has been used historically by the DEQ (formerly the Department of Natural Resources [DNR]) as well as the Environmental Protection Agency (EPA) to evaluate the assumption of normality (DNR, 1994; EPA, 1989c). However, questions have been raised about the usefulness of using the CV for this purpose (EPA 1992c). The CV is sensitive to biased estimates of the mean should be used cautiously for censored data. As a measure of symmetry or asymmetry, the coefficient of skewness (Section 1.3.2) provides a more reliable tool. Furthermore, the Shapiro-Wilk and Shapiro-Francia tests (Sections 1.3.5 and 1.3.6, respectively) provide a better assessment of normality. **Consequently, it is recommended that the CV be calculated and interpreted together with the other methods presented below. Decisions regarding statistical distribution should not be made based solely on the CV.**

Procedure 1.1 Calculation of the Coefficient of Variation

To evaluate for normality, calculate the CV using the following equations. To evaluate for lognormality, first define y = ln(x) and use these y (log-transformed) values in place of the x values in the equations below. For nondetects, substitute 1/2 of the detection limit up to 50% nondetects.

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad \text{Equation 1.1}$$

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}} \qquad \text{Equation 1.2}$$

$$CV = \frac{s}{\bar{x}} \qquad \text{Equation 1.3}$$

Where n represents the sample size, x_i represents the i th observed value, s represents the sample standard deviation, and $\bar{x}$ represents the sample mean. Note: The CV is often reported as a percentage (i.e., 100 times the CV calculated above).



It should not be necessary to calculate the above equations by hand considering the availability of basic statistical computations in statistical software packages and most spreadsheet packages. Most statistical software packages provide the CV as well as the sample standard deviation (s) and the sample mean ($\bar{x}$) together with other common summary statistics. Alternatively, Microsoft Excel can be used to obtain s and $\bar{x}$ for use in Equation 1.3. The Excel functions that should be used to obtain s and $\bar{x}$, respectively, are:

=STDEV(data range)

=AVERAGE(data range)

Note: The Excel function =STDEVP(data range) provides the population standard deviation (denominator = n) rather than the sample standard deviation (denominator = n-1). The population standard deviation is only appropriate for use with census data, which represent every unit of a population. In practice, census data are almost never available and the true standard deviation must be estimated. The sample standard deviation is an unbiased estimate of the true standard deviation (i.e., it does not consistently underestimate or overestimate the true standard deviation) and should be used throughout this document in all calculations calling for an estimate of the standard deviation.



Interpretation: If the data come from a normal distribution, then the CV will generally be less than one (EPA, 1989c). However, a CV < 1 does not automatically imply that the data are normal. The other methods described in this chapter must be considered to determine if the normal distribution is appropriate for the data. If the CV > 1, the normal distribution may not provide an adequate model for the data. If the data come from a lognormal or some other distribution, then the CV will likely be greater than one. A log-transformation of the data set will decrease the CV if the data come from a lognormal distribution.

Example 1.1 Sample Calculation of the Coefficient of Variation

At a *FACILITY*, 20 soil samples were collected for analysis of nickel concentrations. The results are shown below in parts per billion (ppb).

	A	B	C	D
1	Observation	Nickel concentration (ppb)	Ln (Nickel conc.)	
2	1	58.8	4.074	=LN(B2)
3	2	1.0	0.000	=LN(B3)
4	3	262.0	5.568	=LN(B4)
5	4	56.0	4.025	⋮
6	5	8.7	2.163	
7	6	19.0	2.944	
8	7	81.5	4.401	
9	8	331.0	5.802	
10	9	14.0	2.639	
11	10	64.4	4.165	
12	11	39.0	3.664	
13	12	151.0	5.017	
14	13	27.0	3.296	
15	14	21.4	3.063	
16	15	578.0	6.360	
17	16	3.1	1.131	
18	17	942.0	6.848	
19	18	85.6	4.450	
20	19	10.0	2.303	
21	20	637.0	6.457	
22				
23	n:	20	20	
24	Mean:	169.5	3.9	
25	Std. Dev:	259.72	1.80	
26	CV:	1.53	0.46	
27	Skewness:	2.00	-0.27	
28				
29				
30		=count(B2:B21)	=count(C2:C21)	
31		=average(B2:B21)	=average(C2:C21)	
32		=stdev(B2:B21)	=stdev(C2:C21)	
33		=B25/B24	=C25/C24	
34		=skew(B2:B21)	=skew(C2:c21)	

Coefficients of variation were calculated for both the raw data and the log-transformed data. First, the averages and standard deviations were calculated using the Microsoft Excel functions shown above. The CV was then calculated by dividing the standard deviations by their respective mean concentrations, which may be denoted CV_{Raw} and CV_{Ln}, respectively.

Since the CV for the raw nickel concentrations is greater than 1 (CV_{Raw}=1.53), this indicates that the data set may not be normally distributed. The CV for the log-transformed data set is less than 1 (CV_{Ln}=0.46), suggesting that it is more appropriate to assume that the data come from a lognormally distributed population. A final decision regarding the distribution of the data set will be made after considering the results of other methods presented throughout this section.

1.3.2 Coefficient of Skewness

The coefficient of skewness (Skew; also denoted γ_1) measures the skewness or asymmetry of a data set with respect to the mean. It is relatively easy to compute and it can be useful in evaluating symmetry.

The following coefficients of skewness may be expected for the various types of distributions:

Distribution Type	Coefficient of Skewness
Symmetric (e.g., normal distribution)	Zero (i.e., Skew = 0)
Right-skewed (with a long right tail)	Positive (i.e., Skew > 0)
Left-skewed (with a long left tail)	Negative (i.e., Skew < 0)

Right-skewed distributions are common in environmental data analysis (i.e., Skew > 0).

Procedure 1.2 (following page) describes the method for calculating the coefficient of skewness and recommendations for interpretation.

Example 1.2 Sample Calculation of the Coefficient of Skewness

Nickel concentrations from 20 soil samples collected at a *FACILITY* were presented in Example 1.1.

The coefficient of skewness was calculated for both the raw and log-transformed data using the Excel function shown in Example 1.1. The results obtained were as follows:

$$Skew_{Raw} = 2.00$$

$$Skew_{Ln} = -0.27$$

$Skew_{Raw}$ is a positive number, indicating that the data set is positively or right skewed, as is common with environmental data sets. Because $Skew_{Raw}$ is greater than 1, the data may not be normally distributed.

Since $-1 < Skew_{Ln} < 1$, the data may be lognormally distributed.

Procedure 1.2 Calculation of the Coefficient of Skewness

To evaluate for normality, the coefficient of skewness may be calculated using the following equation. To evaluate for lognormality, first define y = ln(x) and use these y (log-transformed) values in place of the x values in the equation below. For nondetects, substitute 1/2 of the detection limit up to 50% nondetects.

$$Skew = \frac{\frac{n}{(n-1)(n-2)}\sum_{i=1}^{n}(x_i - \bar{x})^3}{s^3} \qquad \text{Equation 1.4}$$

Where n represents the sample size, x_i represents the i th observation, $\bar{x}$ represents the arithmetic mean (Equation 1.1), and s represents the sample standard deviation (Equation 1.2).



Most statistical software packages calculate the coefficient of skewness. Alternatively, Microsoft Excel can be used to obtain the coefficient of skewness, as follows:

=SKEW(data range)



Interpretation: Small degrees of skewness may not affect the results of an analysis conducted using an assumption of normality; however, a large coefficient of skewness may lead to inaccurate results. In general, if -1 < Skew < 1, the normal distribution may provide a reasonable approximation of the data. If Skew > 1 or Skew < -1, the data may not be normally distributed. When calculating the coefficient of skewness for both the raw data set and the log-transformed (Ln) data set, the results (which may be denoted $Skew_{Raw}$ and $Skew_{Ln}$, repsectively) may be interpreted as follows:

- If $Skew_{Raw} > 1$ and $Skew_{Ln} > 1$, the data set is highly skewed and may not represent either a normal or lognormal distribution.
- If $Skew_{Raw} > 1$ but $-1 < Skew_{Ln} < 1$, the raw data are right-skewed, but the log-transformed data are approximately symmetric. This is evidence for the assumption of lognormality for the raw data set.
- If $-1 < Skew_{Raw} < 1$ and $-1 < Skew_{Ln} < 1$, but $|Skew_{Raw}| > |Skew_{Ln}|$, the log-transformed data set is more symmetric. Consequently, an assumption of lognormality may be more appropriate for the data. (Note: $|Skew_{Raw}|$ denotes the absolute value of the skewness of the raw, non-transformed data.)

It is also possible to obtain a Skew < -1. This may be due to the presence of one or more low outliers or simply sampling variability. If a data set is negatively skewed, a log-transformation of the data will not improve the symmetry. If Skew < -1 and the raw data fail a formal test of normality, a conclusion regarding the distribution cannot be drawn. It may be necessary to consult a professional statistician and/or *PROPOSE* an alternate statistical method to compare *FACILITY* data (see Chapter 3).

1.3.3 Normal Probability Plots

One of the best tools for evaluating a data set for normality (or lognormality) is the normal probability plot. This tool allows for visual inspection of the data as well as an assessment of the fit to a specific probability distribution. Irregularities in the data when compared to a known probability distribution are easy to identify.

Normal probability plots are typically constructed by plotting concentration measurements sorted in increasing order along the y-axis versus corresponding quantiles or "z-scores" of a standard normal distribution (i.e., a normal distribution with a mean of zero and a standard deviation of one, also denoted N(0,1)) on the x-axis. If the data are normal, the plotted data points will approximate a straight line. If the data are not normal, departures from normality may be evident as bends or curves in the plotted points. In addition, unusual values, such as outliers, are often identifiable on the resulting plot.

Normal probability plots may also be used to evaluate a data set for lognormality by constructing a probability plot using a natural log transformation of the analytical results instead of the raw (untransformed) analytical results. **It is recommended that probability plots be constructed for both raw (untransformed) and log-transformed (Ln) data and compared to identify the best-fitting distribution.**

Because interpretation of probability plots may be somewhat subjective, conclusions should not be drawn regarding statistical distributions based on probability plots alone. Probability plots should be used in combination with the other methods described in this chapter.



Many statistical packages can create normal probability plots at the click of a button. (The axes may be reversed or may differ slightly from those described below; however, they may be interpreted in the same manner.) Different statistical software packages may refer to these plots by alternate names, such as "normal probability plots," "normal quantile-quantile plots," or "QQ normal plots." For those without access to a statistical package, spreadsheets provide an alternative means to construct probability plots. The instructions are straightforward and are provided in Procedure 1.3.

Procedure 1.3 Construction of a Normal Probability Plot

To evaluate for normality, complete the steps below using the raw data. To evaluate for lognormality, first define y = ln(x) and use these y (log-transformed) values in place of the x values below. For nondetects, substitute 1/2 of the detection limit. Probability plots may be constructed using data with more than 50% nondetects; however, as the percent nondetects increases, the amount of information provided by the plot decreases.

1. Order the data from the smallest to the largest value ($x_{(i)}$, i = 1, …, n).

2. Calculate the cumulative probabilities corresponding to each $x_{(i)}$ (representing the proportion of values less than or equal to $x_{(i)}$) as follows:

3.
$$p_i = \frac{i}{n+1} \qquad \text{Equation 1.5}$$

Where n represents the sample size and i represents the rank of the i th ordered concentration.

4. Determine the quantiles or z-scores from the standard normal distribution corresponding to the cumulative probabilities in Step 2.

5.
$$z_i = \Phi^{-1}(p_i) \qquad \text{Equation 1.6}$$

where Φ^{-1} denotes the inverse of the cumulative standard normal distribution. These values are easily calculated using Excel (see below).

6. Plot z_i (z-scores) versus $x_{(i)}$ (the ordered concentrations for each sample).



Microsoft Excel can be used to plot the above results as well as obtain z-scores (Equation 1.6) for each probability p_i using the following function:

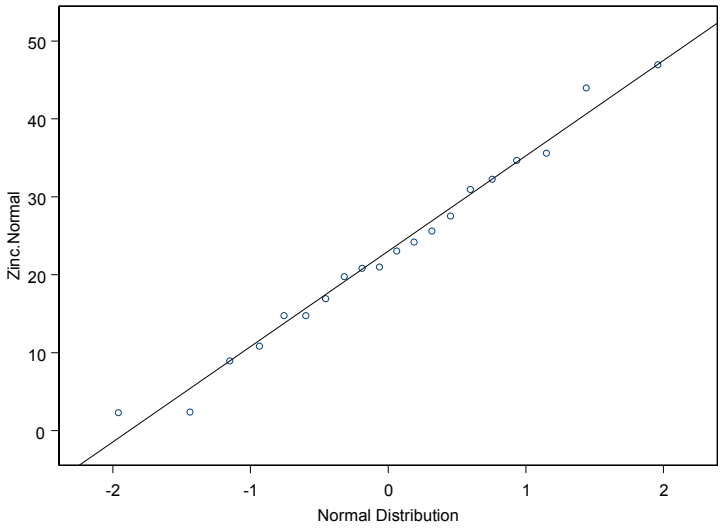
=NORMSINV(p_i)



Interpretation: If a data set is approximately normal, the plotted points should fall on or near a straight line. Curves or bends in the line indicate that the data are not normally distributed. Lognormality of the data set can be evaluated by plotting the log-transformed y-values in place of the x-values above. If the data set is approximately lognormal and the probability plot is constructed using log-transformed data, the plotted points should fall on or near a straight line.

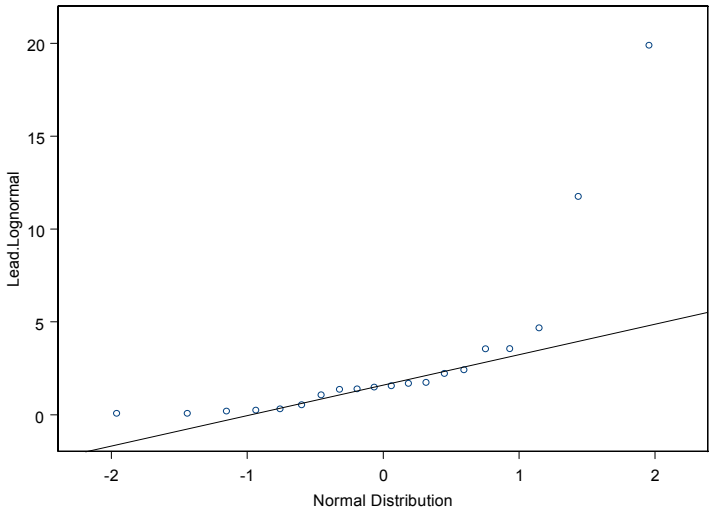
Sample plots are shown on Figures 1.4 through 1.8 to illustrate typical patterns that may be observed on probability plots. Interpretations are provided to the right of each plot. Figures 1.4 through 1.8 were created using the statistical software package S-PLUS. Figures 1.9 and 1.10 (Example 1.3) were constructed using Microsoft Excel.

Figure 1.4 Normal Probability Plot of Zinc Data



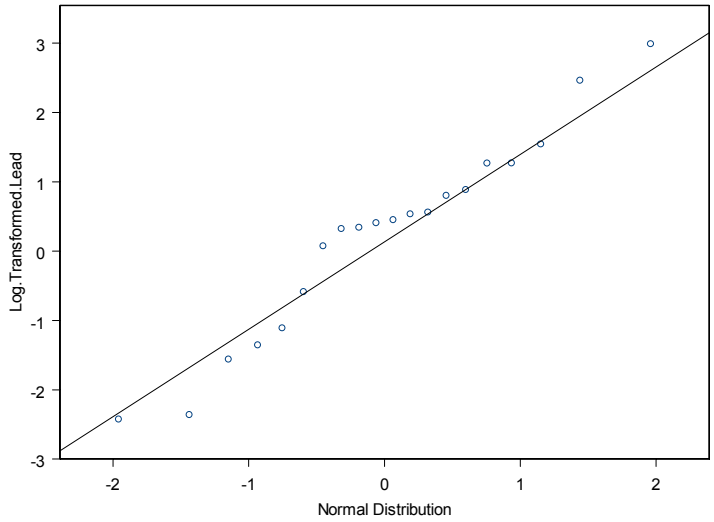
Using raw (untransformed) data, the points fall approximately on a straight line. Therefore, the data set appears to be approximately normally distributed.

Figure 1.5 Normal Probability Plot of Lead Data



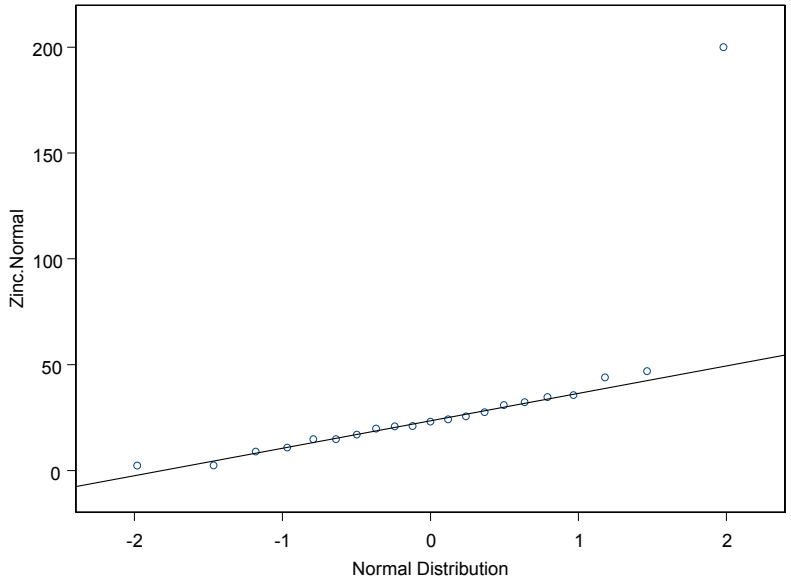
Using raw lead data, the points curve about the straight line. This may indicate that the data are approximately lognormal instead. Compare to the plot constructed using log-transformed data below.

Figure 1.6 Normal Probability Plot of Log-Transformed (Ln) Lead Data



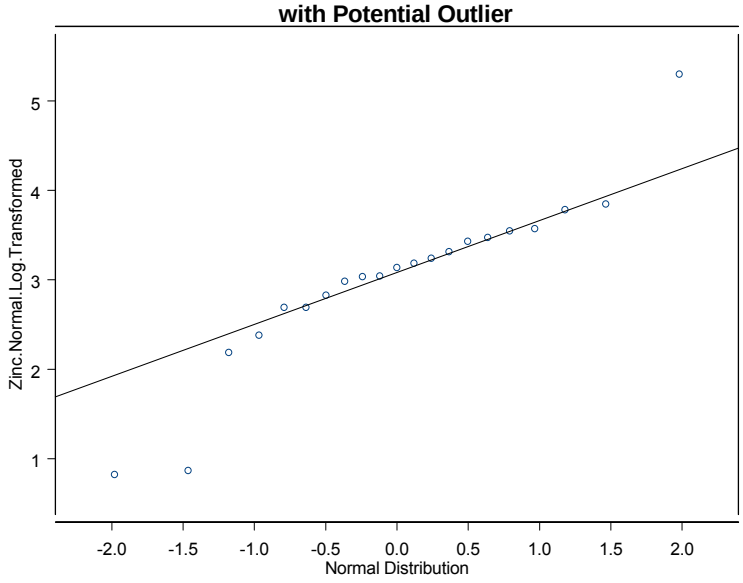
Using log-transformed lead data, the points fall approximately on a straight line. Because the log-transformed data are approximately normal, it can be concluded that the raw (untransformed) data set is approximately lognormal.

Figure 1.7 Normal Probability Plot of Zinc Data with Potential Outlier



Although one might initially guess this data set is lognormally distributed, this plot does not illustrate the characteristic curve of a data set that is lognormally distributed. Most of the data fall on or near a straight line; however, one outlying value is evident. This indicates that the data may be normally distributed with the exception of a single outlier.

Figure 1.8 Normal Probability Plot of Log-Transformed Zinc Data with Potential Outlier



The data shown in Figure 1.7 were log-transformed to illustrate that log-transformations do not always solve problems with high outliers. The high value still stands out as a potential outlier in this plot. Furthermore, note that two low values now appear to be outlying results as well.

The data set shown in Figures 1.7 and 1.8 are evaluated further in Chapter 2 on identification of outliers.

Example 1.3 Sample Construction of a Probability Plot

The nickel data set from Example 1.1 was used to create probability plots for both the raw nickel concentrations and the log-transformed concentrations. Microsoft Excel was used to complete the calculations described in Procedure 1.3 (calculations shown below) and to plot the results. Column D was plotted versus Column C to create the probability plot for the raw (untransformed) data set (Figure 1.9). Column E was plotted versus Column C to create the normal probability plot for log-transformed (Ln) data (Figure 1.10).

	A	B	C	D	E
1			Normal		
2	Order (i)	i / (n+1)	quantile	Nickel conc. (ppb)	Ln (Nickel conc.)
3	1	0.05	-1.67	1.0	0.000
4	2	0.10	-1.31	3.1	1.131
5	3	0.14	-1.07	8.7	2.163
6	4	0.19	-0.88	10.0	2.303
7	5	0.24	-0.71	14.0	2.639
8	6	0.29	-0.57	19.0	2.944
9	7	0.33	-0.43	21.4	3.063
10	8	0.38	-0.30	27.0	3.296
11	9	0.43	-0.18	39.0	3.664
12	10	0.48	-0.06	56.0	4.025
13	11	0.52	0.06	58.8	4.074
14	12	0.57	0.18	64.4	4.165
15	13	0.62	0.30	81.5	4.401
16	14	0.67	0.43	85.6	4.450
17	15	0.71	0.57	151.0	5.017
18	16	0.76	0.71	262.0	5.568
19	17	0.81	0.88	331.0	5.802
20	18	0.86	1.07	578.0	6.360
21	19	0.90	1.31	637.0	6.457
22	20	0.95	1.67	942.0	6.848
23					
24					
25		=A3/21	=NORMSINV(B3)		=LN(D3)
26		=A4/21	=NORMSINV(B4)		=LN(D4)
27		⋮	⋮		⋮

Figure 1.9 Normal Probability Plot of Raw Nickel Data (Plotted Using Microsoft Excel)

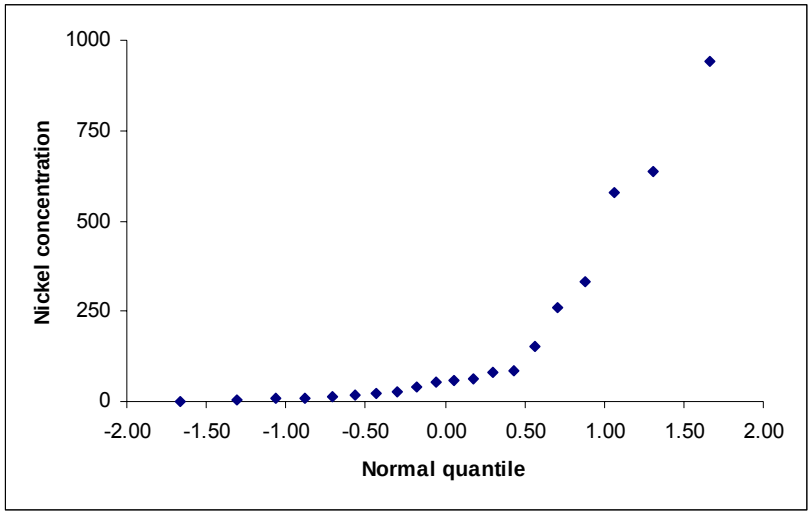
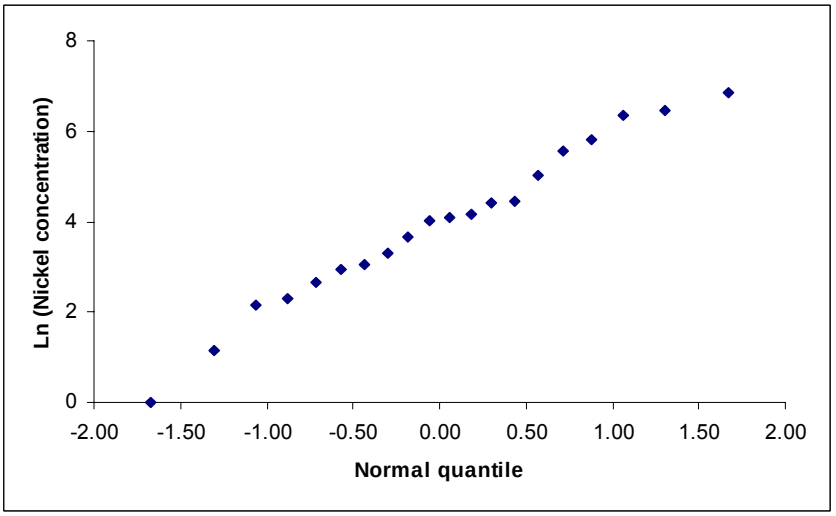


Figure 1.10 Normal Probability Plot of Log-Transformed Nickel Concentrations (Plotted Using Microsoft Excel)



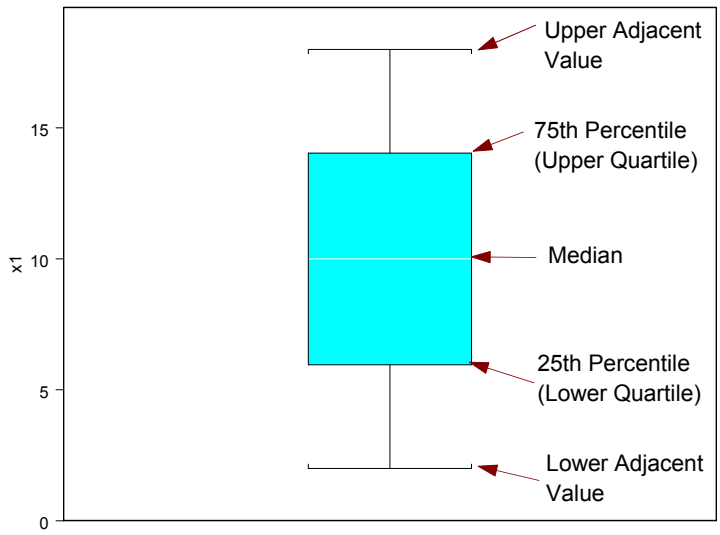
Review of the probability plots indicates that the lognormal distribution provides a better fit to the nickel concentrations than the normal distribution. The plot of the raw data in Figure 1.9 illustrates the distinct curve often seen when the data are better approximated by the lognormal distribution. However, the plot of the log-transformed data closely approximates a straight line. This indicates that the log-transformed nickel concentrations are approximately normal, thus the raw data are approximately lognormal. These findings are consistent with the conclusions drawn in Examples 1.1 and 1.2.

1.3.4 Box Plots

Box plots are another way to graphically examine the characteristics of a data set (see Figure 1.11). The 25th and 75th percentiles of the data set define the lower and upper ends of the box, respectively. A line across the center of the box denotes the median (50th percentile, or middle value). The length of the box, or distance from the 25th to the 75th percentile, is called the interquartile range (IQR).

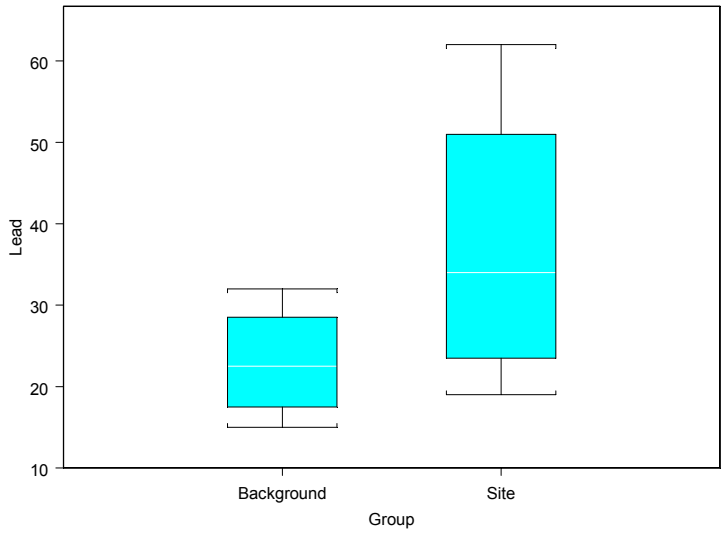
Vertical lines extending from the ends of the box (whiskers) may be constructed in various ways. Two common methods for drawing whiskers are described here. The simplest method involves drawing vertical lines from the upper edge of the box to the maximum concentration and from the lower edge of the box to the minimum concentration.

Figure 1.11 Box and Whisker Plot



A second method involves drawing vertical lines from the upper edge of the box to the next larger value within one step (i.e., the upper adjacent value) and from the 25th percentile down to the next smaller value within one step (i.e., the lower adjacent value). A step is traditionally defined as 1.5 times the IQR. This step size is useful in that the outside values shown as asterisks or horizontal lines beyond the whiskers are potential outliers, though formal verification as described in Chapter 2 is required. This screening criteria can be made more or less strict by changing the step size.

Figure 1.12 Side-by-Side Box Plots



Box plots are particularly useful when comparing two or more data sets. Side-by-side box plots can be inspected for differences between the data sets (Figure 1.12).

Since interpretation of box plots can be somewhat subjective, box plots should only be used in combination with other methods for determining the distribution of a data set, not as a sole determining factor.



Although Microsoft Excel does not currently have capabilities to produce box plots, most statistical software packages (e.g., S-Plus, Minitab, Statistica, Systat, SPSS, and SAS) can easily produce box plots with the click of a button or a few command lines of code.



Interpretation: Box plots provide another useful tool for examining the statistical distributions of data sets. The horizontal line dividing the box graphically shows the median or middle value of a data set. The length of the box provides information on the variability or spread in the data set (similar to the CV). Skewness (i.e., symmetry versus asymmetry) can be inferred by examining the relative lengths of the box halves. For example, if the portion of the box and/or whiskers above the median are longer than the portion of the box and/or whiskers below the median, the data set is right-skewed (i.e., asymmetric, with a long right tail).

Box plots also provide an easy way to identify any unusual values (e.g., potential outliers) in the data set since outside values are often shown as asterisks or horizontal lines beyond the whiskers.

1.3.5 Shapiro-Wilk Test for Normality ($n \leq 50$)

The Shapiro-Wilk (SW) Test for normality (Shapiro and Wilk, 1965) is recommended as a formal test of normality when the data set contains 50 or fewer results. As noted by the EPA (1992c), the SW Test is considered to be one of the very best tests of normality available (Miller, 1986; Madansky, 1988). Essentially, the SW Test for normality provides a measure of the degree to which a probability plot approximates a straight line. When the probability plot shows a nearly straight line, the SW Test statistic will be large. Conversely, when the probability plot shows substantial bends or curves, the SW Test statistic will be small.

As previously discussed, various statistical guidance documents provide recommendations to consider default assumptions of normality or lognormality (i.e., test first for normality or lognormality; if the data pass a test for the default distribution, no further testing is recommended). **However, it is recommended here that the SW Test be completed both on the raw data and on the log-transformed (Ln) data. The results of these two tests should be compared to determine which distribution provides a better fit to the data.**

Most statistical software packages include tests of statistical distributions; although not all include the SW Test. Of those that include this test, not all include the same version of the test. Consequently, care should be exercised. EnvironmentalStats for S-PLUS provides this test along with several supplemental graphics that are available with a few clicks of a button. For those without access to a statistical package, spreadsheets provide an alternative means for completing the SW Test. Instructions for Microsoft Excel are provided in Procedure 1.4.

Procedure 1.4 Shapiro-Wilk Test for Normality (n ≤ 50)

To test for normality, follow the steps below. To test for lognormality, first define y = ln(x) and use these y (transformed) values in place of the x values below. For nondetects, substitute 1/2 of the detection limit up to 50% nondetects.

1. Order the data from the smallest to the largest value, where $x_{(1)}$ is the smallest value (also called the first order statistic), $x_{(2)}$ is the next largest value, …, and $x_{(n)}$ is the largest value.

2. Set *k* equal to the largest integer less than or equal to (*n*/2), where n represents the sample size.

3. Calculate the differences $[x_{(n-i+1)} - x_{(i)}]$ for each $i = 1, 2, \ldots, k$.

4. Find the coefficients a_i for i = 1, 2, …, *k* using Table 1.1. Coefficients are provided in this table for samples sizes from *n* = 3 to *n* = 50.

5. Calculate *b* as follows:

$$b = \sum_{i=1}^{k} b_i = \sum_{i=1}^{k} a_{n-i+1}(x_{(n-i+1)} - x_{(i)}) \qquad \text{Equation 1.7}$$

6. Calculate the sample standard deviation (*s*) of the data set (Equation 1.2).



Microsoft Excel can be used to obtain an estimate of the sample standard deviation (*s*) using the following function:

=STDEV(data range)

7. Calculate the Shapiro-Wilk test statistic as follows:

$$SW = \left[\frac{b}{s\sqrt{n-1}}\right]^2 \qquad \text{Equation 1.8}$$

8. Using Table 1.2 and a significance level of $\alpha = 0.05$, determine the critical value (sw_α) based on *n* observations and compare to *SW*.



Interpretation: The value SW will tend to be large when a probability plot of the data approximates a straight line. SW will tend to be small when a probability plot shows substantial departures from a straight line (e.g., bends, curves, or outliers). Specifically:

- If $SW \geq sw_\alpha$ conclude that the data set is approximately normal (lognormal, if calculated using y values).
- If $SW < sw_\alpha$ conclude that the data set is **not** normally (lognormally) distributed.

***p*-Values:** Some statistical software packages provide *p*-values instead of the *SW* and sw_α values described above. The *p*-value may be interpreted as the probability that the given data set and the corresponding *SW* value would be obtained if the sampled population (i.e., the population that was sampled to obtain the data set) were truly normally distributed (or lognormally distributed, if testing for lognormality). For example, if a raw or untransformed data set was tested for normality and the resulting *p*-value was small, it is unlikely that the data set was obtained from a normal distribution. When the significance level is set at $\alpha = 0.05$ (the recommended level of significance for most situations), the p-value should be compared directly to this value. That is:

If $p \geq 0.05$, conclude that the data set is approximately normal (lognormal, if obtained using y values).

If $p < 0.05$, conclude that the data set is **not** normally (lognormally) distributed.

As previously noted, the SW Test should be completed for both the raw data set and the log-transformed (Ln) data set to test for normality and lognormality, respectively. If the results indicate that the data pass both tests, the test resulting in the higher *SW* value (or *p*-value) should be relied upon to draw conclusions about the distribution of the data.

A review of plots and summary statistics should also be completed to confirm the results of the SW Test.

In some cases, data sets fail both tests for normality and lognormality. When the SW Test results in a conclusion that a data set is not normal or lognormal, it does not indicate which characteristic(s) of the data, say skewness to a heavy-tailed distribution (or both) was responsible for the lack of normality or lognormality. Inspection of the histogram, box plot, and particularly the probability plot, may provide some insight as to why this occurred. It may be clear that the data set is highly skewed, even when log-transformed. If there is a potential outlier in the data set, see Chapter 2 of this section for specific recommendations. The presence of a true outlier(s) may be an indication of an unsuspected *HOT SPOT*. *HOT SPOTS* generally represent a separate population and must be addressed separately. If there is no clear reason for the data to fail tests of normality and lognormality, it may be necessary to proceed to an alternate statistical method for comparing *FACILITY* data to Part 201 criteria or *BACKGROUND*, as described in Chapters 3 and 4. Consultation with a professional statistician is advised.

Example 1.4 Sample Shapiro-Wilk Test for Normality

Based on the evaluations presented in Examples 1.1, 1.2, and 1.3, the nickel concentrations in soil appear to fit a lognormal distribution better than a normal distribution pattern. To formally test this, the SW Test was conducted on both the raw data and the log-transformed data.

Calculations for the Shapiro-Wilk Test of Normality (Raw Data)

	A	B	C	D	E	F	G
1	i	$x_{(i)}$	$x_{(n-i+1)}$	$x_{(n-i+1)} - x_{(i)}$	$a_{(n-i+1)}$	$b_{(i)}$	
2	1	1.0	942.0	941.0	0.4734	445.4694	← =D2*E2
3	2	3.1	637.0	633.9	0.3211	203.5453	← =D3*E3
4	3	8.7	578.0	569.3	0.2565	146.0255	← =D4*E4
5	4	10.0	331.0	321.0	0.2085	66.9285	⋮
6	5	14.0	262.0	248.0	0.1686	41.8128	
7	6	19.0	151.0	132.0	0.1334	17.6088	
8	7	21.4	85.6	64.2	0.1013	6.5035	
9	8	27.0	81.5	54.5	0.0711	3.8750	
10	9	39.0	64.4	25.4	0.0422	1.0719	
11	10	56.0	58.8	2.8	0.0140	0.0392	
12	11	58.8	56.0		b:	932.880	
13	12	64.4	39.0			=SUM(F2:F11)	
14	13	81.5	27.0				
15	14	85.6	21.4				
16	15	151.0	19.0				
17	16	262.0	14.0				
18	17	331.0	10.0				
19	18	578.0	8.7				
20	19	637.0	3.1				
21	20	942.0	1.0				
22							
23	Std. Dev:	259.7	← =STDEV(B2:B21)				
24	n:	20	← =COUNT(B2:B21)				
25	k:	10					

$$W = \left[\frac{932.9}{259.7\sqrt{19}}\right]^2 = 0.679$$

Calculations for the Shapiro-Wilk Test of Normality (Log-Transformed Data)

	A	B	C	D	E	F	G
1	i	$x_{(i)}$	$x_{(n-i+1)}$	$x_{(n-i+1)} - x_{(i)}$	$a_{(n-i+1)}$	$b_{(i)}$	
2	1	0.0	6.8	6.8	0.4734	3.2418	← =D2*E2
3	2	1.1	6.5	5.3	0.3211	1.7100	← =D3*E3
4	3	2.2	6.4	4.2	0.2565	1.0763	← =D4*E4
5	4	2.3	5.8	3.5	0.2085	0.7297	⋮
6	5	2.6	5.6	2.9	0.1686	0.4939	
7	6	2.9	5.0	2.1	0.1334	0.2765	
8	7	3.1	4.4	1.4	0.1013	0.1404	
9	8	3.3	4.4	1.1	0.0711	0.0785	
10	9	3.7	4.2	0.5	0.0422	0.0212	
11	10	4.0	4.1	0.0	0.0140	0.0007	
12	11	4.1	4.0		b:	7.769	
13	12	4.2	3.7			=SUM(F2:F11)	
14	13	4.4	3.3				
15	14	4.4	3.1				
16	15	5.0	2.9				
17	16	5.6	2.6				
18	17	5.8	2.3				
19	18	6.4	2.2				
20	19	6.5	1.1				
21	20	6.8	0.0				
22							
23	Std. Dev:	1.8	← =STDEV(B2:B21)				
24	n:	20	← =COUNT(B2:B21)				
25	k:	10					

$$W = \left[\frac{7.769}{1.8\sqrt{19}}\right]^2 = 0.980$$

From Table 1.2, it can be seen that the critical value sw_α, given a sample size of 20, is 0.905 at the α = 0.05 level. The SW statistic calculated from the raw nickel data (SW_{Raw}) is equal to 0.679. The SW statistic calculated using the log-transformed data (SW_{Ln}) is equal to 0.980. Because $SW_{Raw} < sw_\alpha$ (0.679 < 0.905), it can be concluded that the data are not normally distributed. However, because $SW_{Ln} > sw_\alpha$ (0.980 > 0.905), it can be concluded that the data are approximately lognormally distributed.

The results of the SW Test confirm our initial conclusions based on use of summary statistics and plots. Consequently, we can be more confident in our conclusion that the lognormal model provides a better approximation to the data. Inference made under the assumption of lognormality is expected to be more reliable than under the assumption of normality.

1.3.6 Shapiro-Francia Test for Normality (*n* > 50)

When a data set is large (i.e., data sets with more than 50 observations), the Shapiro-Francia (SF) Test for normality is appropriate (Shapiro and Francia, 1972). Similar to the SW Test, the SF Test statistic will be a large when a probability plot of the data shows a nearly straight line.

EnvironmentalStats for S-PLUS provides the SF Test for normality (or lognormality) along with several supplemental graphics that are available with a few clicks of a button. For those without access to a statistical package, spreadsheets provide an alternative means for completing the SF Test. Instructions for Microsoft Excel are provided in Procedure 1.5.

The SF Test should be completed for both the raw data set and the log-transformed (Ln) data set to test for normality and lognormality, respectively. If the results indicate that the data pass both tests, the test resulting in the higher SF value should be relied upon to draw conclusions about the distribution of the data.

A review of plots and summary statistics should also be completed to confirm the results of the SF Test.

In some cases, data sets fail both tests for normality and lognormality. When the SF Test results in a conclusion that a data set is not normal or lognormal, it does not indicate which characteristic(s) of the data, say skewness to a heavy-tailed distribution (or both) was responsible for the lack of normality or lognormality. Inspection of the histogram, box plot, and particularly the probability plot, may provide some insight as to why this occurred. It may be clear that the data set is highly skewed, even when log-transformed. If there is a potential outlier in the data set, see Chapter 2 of this section for specific recommendations. The presence of a true outlier(s) may be an indication of an unsuspected *HOT SPOT*. *HOT SPOTS* generally represent a separate population and must be addressed separately. If there is no clear reason for the data to fail tests of normality and lognormality, it may be necessary to proceed to an alternate statistical method for comparing *FACILITY* data to Part 201 criteria or *BACKGROUND*, as described in Chapters 3 and 4. Consultation with a professional statistician is advised.

Procedure 1.5 Shapiro-Francia Test for Normality (n > 50)

To test for normality, follow the steps below. To test for lognormality, first define y = ln(x) and use these y (transformed) values in place of the x values below. Substitute 1/2 of the detection limit for nondetects for up to 50% nondetects.

1. Order the data from the smallest to the largest value, where $x_{(1)}$ is the smallest value (also called the first order statistic), $x_{(2)}$ is the next largest value, …, and $x_{(n)}$ is the largest value.

2. Calculate the sample standard deviation (s^2) using Equation 1.2 and squaring the result.



Microsoft Excel can be used to obtain an estimate of the sample variance (s^2) using the following function:

=VAR(data range)

3. Calculate m_i, or i th ordered normal quantiles (z-scores) using:

$$m_i = \Phi^{-1}\left(\frac{i}{n+1}\right) \qquad \text{Equation 1.9}$$

Where Φ^{-1} denotes the inverse of the cumulative standard normal distribution.



Microsoft Excel can be used to obtain z-scores (m_i) for each value using the following function:

m_i =NORMSINV$\left(\frac{i}{n+1}\right)$

4. The SF Test statistic is calculated using the following formula:

$$SF = \left[\sum_{i=1}^{n} m_i x_{(i)}\right]^2 \Bigg/ \left[(n-1)s^2 \sum_{i=1}^{n} m_i^{\,2}\right] \qquad \text{Equation 1.10}$$

5. Using Table 1.3 and a significance level of α = 0.05, determine the critical value (sf_α) based on n observations and compare to SF.



Interpretation: Similar to the SW statistic, the value of the SF statistic will tend to be large when a probability plot of the data approximates a straight line. SF will tend to be small when a probability plot shows substantial departures from a straight line (e.g., bends, curves, or outliers). Specifically:

- If $SF \geq sf_\alpha$ conclude that the data set is approximately normal (lognormal, if calculated using y values).
- If $SF < sf_\alpha$ conclude that the data set is **not** normally (lognormally) distributed.

***p*-Values:** Some statistical software packages provide *p*-values instead of the *SF* and sf_α values described above. The *p*-value may be interpreted as the probability that the given data set and the corresponding *SF* value would be obtained if the sampled population (i.e., the population that was sampled to obtain the data set) were truly normally distributed (or lognormally distributed, if testing for lognormality). For example, if a raw or untransformed data set was tested for normality and the resulting *p*-value was small, it is unlikely that the data set was obtained from a normal distribution. When the significance level is set at $\alpha = 0.05$ (the recommended level of significance for most situations), the p-value should be compared directly to this value. That is:

If $p \geq 0.05$, conclude that the data set is approximately normal (lognormal, if obtained using y values).

If $p < 0.05$, conclude that the data set is **not** normally (lognormally) distributed.

As previously noted, the SF Test should be completed for both the raw data set and the log-transformed (Ln) data set to test for normality and lognormality, respectively. If the results indicate that the data pass both tests, the test resulting in the higher *SF* value (or *p*-value) should be relied upon to draw conclusions about the distribution of the data.

Example 1.5 Sample Shapiro-Francia Test for Normality

Fifty-two samples of soil dioxin (in ppb) were collected at a hypothetical *FACILITY*. Probability plots, the coefficient of skewness, and the CV all suggested that the data were lognormally distributed. A SF Test was then conducted to formally test whether the data were lognormally distributed.

The results were SF_{Ln} = 0.9763 and SF_{Raw} = 0.7682 (only the calculations for the log-transformed data set are shown in the figure). The sf_α for n = 52 and α = 0.05 is 0.955. Since $SF_{Ln} > sf_\alpha$, we conclude that the dioxin data set is lognormally distributed.

Calculations for Shapiro-Francia Test on Example Data Set

	A	B	C	D	E	F	G	H	I	J
1	Observation	Ln (Dioxin)	i / (n + 1)	Quantiles (m_i)	$m_i * x_{(i)}$	m_i^2				
2	1	0.07	0.02	-2.08	-0.14	4.32		n:	52	
3	2	0.36	0.04	-1.78	-0.64	3.16			=COUNT(B2:B53)	
4	3	0.41	0.06	-1.58	-0.65	2.51				
5	4	0.61	0.08	-1.44	-0.88	2.06		s^2:	0.83	
6	5	0.69	0.09	-1.31	-0.91	1.73			=VAR(B2:B53)	
7	6	0.73	0.11	-1.21	-0.89	1.46				
8	7	0.79	0.13	-1.12	-0.88	1.25		SF:	0.9763	
9	8	0.86	0.15	-1.03	-0.89	1.07		= E54^2 / (51 * I5 * F54)		
10	9	0.92	0.17	-0.95	-0.88	0.91				
11	10	1.04	0.19	-0.88	-0.92	0.78				
12	11	1.18	0.21	-0.81	-0.97	0.66	$SF = \left[\sum_{i=1}^{n} m_i x_{(i)}\right]^2 \Big/ \left[(n-1)s^2 \sum_{i=1}^{n} m_i^2\right]$			
13	12	1.27	0.23	-0.75	-0.95	0.56				
14	13	1.36	0.25	-0.69	-0.94	0.48				
15	14	1.42	0.26	-0.63	-0.90	0.40				
16	15	1.45	0.28	-0.57	-0.83	0.33				
17	16	1.48	0.30	-0.52	-0.77	0.27				
18	17	1.51	0.32	-0.47	-0.70	0.22				
19	18	1.57	0.34	-0.41	-0.65	0.17				
20	19	1.61	0.36	-0.36	-0.58	0.13				
21	20	1.62	0.38	-0.31	-0.50	0.10				
22	21	1.70	0.40	-0.26	-0.45	0.07				
23	22	1.71	0.42	-0.21	-0.37	0.05				
24	23	1.72	0.43	-0.17	-0.29	0.03				
25	24	1.73	0.45	-0.12	-0.20	0.01				
26	25	1.73	0.47	-0.07	-0.12	0.01				
27	26	1.75	0.49	-0.02	-0.04	0.00				
28	27	1.76	0.51	0.02	0.04	0.00				
29	28	1.77	0.53	0.07	0.13	0.01				
30	29	1.82	0.55	0.12	0.22	0.01				
31	30	1.86	0.57	0.17	0.31	0.03				
32	31	1.94	0.58	0.21	0.42	0.05				
33	32	1.94	0.60	0.26	0.51	0.07				
34	33	1.98	0.62	0.31	0.62	0.10				
35	34	2.02	0.64	0.36	0.73	0.13				
36	35	2.10	0.66	0.41	0.87	0.17				
37	36	2.18	0.68	0.47	1.02	0.22				
38	37	2.40	0.70	0.52	1.25	0.27				
39	38	2.51	0.72	0.57	1.44	0.33				
40	39	2.57	0.74	0.63	1.62	0.40				
41	40	2.65	0.75	0.69	1.83	0.48				
42	41	2.68	0.77	0.75	2.01	0.56				
43	42	2.82	0.79	0.81	2.30	0.66				
44	43	2.90	0.81	0.88	2.56	0.78				
45	44	2.96	0.83	0.95	2.82	0.91				
46	45	3.01	0.85	1.03	3.10	1.07				
47	46	3.09	0.87	1.12	3.45	1.25				
48	47	3.25	0.89	1.21	3.93	1.46				
49	48	3.30	0.91	1.31	4.34	1.73				
50	49	3.44	0.92	1.44	4.94	2.06				
51	50	3.48	0.94	1.58	5.51	2.51				
52	51	3.65	0.96	1.78	6.48	3.16				
53	52	3.78	0.98	2.08	7.86	4.32				
54					43.34	45.44				
55					=SUM(E2:E53)	=SUM(F2:F53)				
56										
57				=NORMSINV(C2)						
58				=NORMSINV(C3)						
59				=NORMSINV(C4)						
60				⋮						
61										

1.3.7 D'Agostino Test for Normality (*n* > 50)

Some EPA statistical guidance documents recommend the D'Agostino Test (D'Agostino, 1971) to test for normality when the sample size is between 50 and 1000. The D'Agostino's test and the Shapiro-Francia test tend to provide similar results and therefore can be considered roughly equivalent. EnvironmentalStats for S-PLUS does not provide a function that performs the D'Agostino Test for normality, but the necessary calculations can easily be performed using a spreadsheet. Both Gibbons (1994) and Gilbert (1987) describe the method and provide the necessary tables. Although the SF Test is preferred, analyses using the D'Agostino Test are acceptable.

1.4 EVALUATING STATISTICAL DISTRIBUTIONS WHEN DATA CONTAIN > 50% NONDETECTS

When the proportion of concentrations below the detection limit is > 50%, evaluation of the probability distribution of the data is not recommended. Therefore, the analyses described in this chapter are generally not needed. However, these methods may still provide some insight, in particular the graphical methods, to the extent that the data contain some detectable concentrations (e.g., a data set with only slightly more than 50% nondetects).

Table 1.1 Coefficients (a_i) for the Shapiro-Wilk Test for Normality for Various Sample Sizes (n). From Shapiro and Wilk, 1965.

i \ n	2	3	4	5	6	7	8	9	10
1	0.7071	0.7071	0.6872	0.6646	0.6431	0.6233	0.6052	0.5888	0.5739
2	-	0.0000	0.1677	0.2413	0.2806	0.3031	0.3164	0.3244	0.3291
3	-	-	-	0.0000	0.0875	0.1401	0.1743	0.1976	0.2141
4	-	-	-	-	-	0.0000	0.0561	0.0947	0.1224
5	-	-	-	-	-	-	-	0.0000	0.0399

i \ n	11	12	13	14	15	16	17	18	19	20
1	0.5601	0.5475	0.5359	0.5251	0.5150	0.5056	0.4968	0.4886	0.4808	0.4734
2	0.3315	0.3325	0.3325	0.3318	0.3306	0.3290	0.3273	0.3253	0.3232	0.3211
3	0.2260	0.2347	0.2412	0.2460	0.2495	0.2521	0.2540	0.2553	0.2561	0.2565
4	0.1429	0.1586	0.1707	0.1802	0.1878	0.1939	0.1988	0.2027	0.2059	0.2085
5	0.0695	0.0922	0.1099	0.1240	0.1353	0.1447	0.1524	0.1587	0.1641	0.1686
6	0.0000	0.0303	0.0539	0.0727	0.0880	0.1005	0.1109	0.1197	0.1271	0.1334
7	-	-	0.0000	0.0240	0.0433	0.0593	0.0725	0.0837	0.0932	0.1013
8	-	-	-	-	0.0000	0.0196	0.0359	0.0496	0.0612	0.0711
9	-	-	-	-	-	-	0.0000	0.0163	0.0303	0.0422
10	-	-	-	-	-	-	-	-	0.0000	0.0140

i \ n	21	22	23	24	25	26	27	28	29	30
1	0.4643	0.4590	0.4542	0.4493	0.4450	0.4407	0.4366	0.4328	0.4291	0.4254
2	0.3185	0.3156	0.3126	0.3098	0.3069	0.3043	0.3018	0.2992	0.2968	0.2944
3	0.2578	0.2571	0.2563	0.2554	0.2543	0.2533	0.2522	0.2510	0.2499	0.2487
4	0.2119	0.2131	0.2139	0.2145	0.2148	0.2151	0.2152	0.2151	0.2150	0.2148
5	0.1736	0.1764	0.1787	0.1807	0.1822	0.1836	0.1848	0.1857	0.1864	0.1870
6	0.1399	0.1443	0.1480	0.1512	0.1539	0.1563	0.1584	0.1601	0.1616	0.1630
7	0.1092	0.1150	0.1201	0.1245	0.1283	0.1316	0.1346	0.1372	0.1395	0.1415
8	0.0804	0.0878	0.0941	0.0997	0.1046	0.1089	0.1128	0.1162	0.1192	0.1219
9	0.0530	0.0618	0.0696	0.0764	0.0823	0.0876	0.0923	0.0965	0.1002	0.1036
10	0.0263	0.0368	0.0459	0.0539	0.0610	0.0672	0.0728	0.0778	0.0822	0.0862
11	0.0000	0.0122	0.0228	0.0321	0.0403	0.0476	0.0540	0.0598	0.6500	0.0697
12	-	-	0.0000	0.0107	0.0200	0.0284	0.0358	0.0424	0.0483	0.0537
13	-	-	-	-	0.0000	0.0094	0.0178	0.0253	0.0320	0.0381
14	-	-	-	-	-	-	0.0000	0.0084	0.0159	0.0227
15	-	-	-	-	-	-	-	-	0.0000	0.0076

Table 1.1 (*continued*) Coefficients (a_i) for the Shapiro-Wilk Test for Normality for Various Sample Sizes (n). From Shapiro and Wilk, 1965.

i \ n	31	32	33	34	35	36	37	38	39	40
1	0.4220	0.4188	0.4156	0.4127	0.4096	0.4068	0.4040	0.4015	0.3989	0.3964
2	0.2921	0.2898	0.2876	0.2854	0.2834	0.2813	0.2794	0.2774	0.2755	0.2737
3	0.2475	0.2462	0.2451	0.2439	0.2427	0.2415	0.2403	0.2391	0.2380	0.2368
4	0.2145	0.2141	0.2137	0.2132	0.2127	0.2121	0.2116	0.2110	0.2104	0.2098
5	0.1874	0.1878	0.1880	0.1882	0.1883	0.1883	0.1883	0.1881	0.1880	0.1878
6	0.1641	0.1651	0.1660	0.1667	0.1673	0.1678	0.1683	0.1686	0.1689	0.1691
7	0.1433	0.1449	0.1463	0.1475	0.1487	0.1496	0.1505	0.1513	0.1520	0.1526
8	0.1243	0.1265	0.1284	0.1301	0.1317	0.1331	0.1344	0.1356	0.1366	0.1376
9	0.1066	0.1093	0.1118	0.1140	0.1160	0.1179	0.1196	0.1211	0.1225	0.1237
10	0.0899	0.0931	0.0961	0.0988	0.1013	0.1036	0.1056	0.1075	0.1092	0.1108
11	0.0739	0.0777	0.0812	0.0844	0.0873	0.0900	0.0924	0.0947	0.0967	0.0986
12	0.0585	0.0629	0.0669	0.0706	0.0739	0.0770	0.0798	0.0824	0.0848	0.0870
13	0.0435	0.0485	0.0530	0.0572	0.0610	0.0645	0.0677	0.0706	0.0733	0.0759
14	0.0289	0.0344	0.0395	0.0441	0.0484	0.0523	0.0559	0.0592	0.0622	0.0651
15	0.0144	0.0206	0.0262	0.0314	0.0361	0.0404	0.0444	0.0481	0.0515	0.0546
16	0.0000	0.0068	0.0131	0.0187	0.0239	0.0287	0.0331	0.0372	0.0409	0.0444
17	-	-	0.0000	0.0062	0.0119	0.0172	0.0220	0.0264	0.0305	0.0343
18	-	-	-	-	0.0000	0.0057	0.0110	0.0158	0.0203	0.0244
19	-	-	-	-	-	-	0.0000	0.0053	0.0101	0.0146
20	-	-	-	-	-	-	-	-	0.0000	0.0049

i \ n	41	42	43	44	45	46	47	48	49	50
1	0.3940	0.3917	0.3894	0.3872	0.3850	0.3830	0.3808	0.3789	0.3770	0.3751
2	0.2719	0.2701	0.2684	0.2667	0.2651	0.2635	0.2620	0.2604	0.2589	0.2574
3	0.2357	0.2345	0.2334	0.2323	0.2313	0.2302	0.2291	0.2281	0.2271	0.2260
4	0.2091	0.2085	0.2078	0.2072	0.2065	0.2058	0.2052	0.2045	0.2038	0.2032
5	0.1876	0.1874	0.1871	0.1868	0.1865	0.1862	0.1859	0.1855	0.1851	0.1847
6	0.1693	0.1694	0.1695	0.1695	0.1695	0.1695	0.1695	0.1693	0.1692	0.1691
7	0.1531	0.1535	0.1539	0.1542	0.1545	0.1548	0.1550	0.1551	0.1553	0.1554
8	0.1384	0.1392	0.1398	0.1405	0.1410	0.1415	0.1420	0.1423	0.1427	0.1430
9	0.1249	0.1259	0.1269	0.1278	0.1286	0.1293	0.1300	0.1306	0.1312	0.1317
10	0.1123	0.1136	0.1149	0.1160	0.1170	0.1180	0.1189	0.1197	0.1205	0.1212
11	0.1004	0.1020	0.1035	0.1049	0.1062	0.1073	0.1085	0.1095	0.1105	0.1113
12	0.0891	0.0909	0.0927	0.0943	0.0959	0.0972	0.0986	0.9980	0.1010	0.1020
13	0.0782	0.0804	0.0824	0.0842	0.0860	0.0876	0.0892	0.0906	0.0919	0.0932
14	0.0677	0.0701	0.0724	0.0745	0.0765	0.0783	0.0801	0.0817	0.0832	0.0846
15	0.0575	0.0602	0.0628	0.0651	0.0673	0.0694	0.0713	0.0731	0.0748	0.0764
16	0.0476	0.0506	0.0534	0.0560	0.0584	0.0607	0.0628	0.0648	0.0667	0.0685
17	0.0379	0.0411	0.0442	0.0471	0.0497	0.0522	0.0546	0.0568	0.0588	0.0608
18	0.0283	0.0318	0.0352	0.0383	0.0412	0.0439	0.0465	0.0489	0.0511	0.0532
19	0.0188	0.0227	0.0263	0.0296	0.0328	0.0357	0.0385	0.0411	0.0436	0.0459
20	0.0094	0.0136	0.0175	0.0211	0.0245	0.0277	0.0307	0.0335	0.0361	0.0386
21	0.0000	0.0045	0.0087	0.0126	0.0163	0.0197	0.0229	0.0259	0.0288	0.0314
22	-	-	0.0000	0.0042	0.0081	0.0118	0.0153	0.0185	0.0215	0.0244
23	-	-	-	-	0.0000	0.0039	0.0076	0.0111	0.0143	0.0174
24	-	-	-	-	-	-	0.0000	0.0037	0.0071	0.0104
25	-	-	-	-	-	-	-	-	0.0000	0.0035

Table 1.2 Critical Values (sw_α, α = 0.05 and α = 0.10) for the Shapiro-Wilk Test for Normality. From Shapiro and Wilk, 1965.

n	$sw_{0.05}$	$sw_{0.10}$
3	0.767	0.789
4	0.748	0.792
5	0.762	0.806
6	0.788	0.826
7	0.803	0.838
8	0.818	0.851
9	0.829	0.859
10	0.842	0.869
11	0.850	0.876
12	0.859	0.883
13	0.866	0.889
14	0.874	0.895
15	0.881	0.901
16	0.887	0.906
17	0.892	0.910
18	0.897	0.914
19	0.901	0.917
20	0.905	0.920
21	0.908	0.923
22	0.911	0.926
23	0.914	0.928
24	0.916	0.930
25	0.918	0.931
26	0.920	0.933
27	0.923	0.935
28	0.924	0.936
29	0.926	0.937
30	0.927	0.939
31	0.929	0.940
32	0.930	0.941
33	0.931	0.942
34	0.933	0.943
35	0.934	0.944
36	0.935	0.945
37	0.936	0.946
38	0.938	0.947
39	0.939	0.948
40	0.940	0.949
41	0.941	0.950
42	0.942	0.951
43	0.943	0.951
44	0.944	0.952
45	0.945	0.953
46	0.945	0.953
47	0.946	0.954
48	0.947	0.954
49	0.947	0.955
50	0.947	0.955

Table 1.3 Critical Values (sf_α, $\alpha = 0.05$) for the Shapiro-Francia Test for Normality. From Shapiro and Francia, 1972.

Sample Size	$sf_{0.05}$
50	0.953
51	0.954
53	0.957
55	0.958
57	0.961
59	0.962
61	0.963
63	0.964
65	0.965
67	0.966
69	0.966
71	0.967
73	0.968
75	0.969
77	0.969
79	0.970
81	0.970
83	0.971
85	0.972
87	0.972
89	0.972
91	0.973
93	0.973
95	0.974
97	0.975
99	0.976

CHAPTER 2: IDENTIFICATION AND TREATMENT OF OUTLIERS

Prior to statistically comparing *FACILITY* data to Part 201 risk-based criteria (Chapter 3) or *BACKGROUND* concentrations (Chapter 4), it is first necessary to evaluate the underlying statistical distribution (Chapter 1) and screen for outliers. In addition, if *FACILITY-SPECIFIC BACKGROUND* data are obtained, these data must also be evaluated as described in Chapter 1 prior to screening for outliers.

The importance of outlier testing is noted by Gilbert (1987), who states that, "statistical tests for outliers are one part of the data validation process wherein data are screened and examined in various ways before being placed in a data bank and used for estimating population parameters or making decisions."

Outliers are typically thought of as values that are extreme with respect to other data values. As stated by Millard and Neerchal (2001), "an outlier can be defined as an observation that is 'far away' from the rest of the observations."

An outlier can occur for various reasons:

- It may be an incorrect value due to errors in sampling, laboratory analysis, data entry or transcription.

- It may be an accurate result that was sampled from a different population than the one previously identified for investigation. For example, a population may be identified as soil concentrations in a 1/4 acre *EXPOSURE UNIT* used to evaluate direct contact exposures. These soil concentrations must representative of a single statistical distribution. If an outlier is identified in a sample collected from this *EXPOSURE UNIT*, it may reflect a different statistical distribution and possibly a *HOT SPOT* that was previously unidentified. Additional characterization may be necessary.

- It may be an accurate but extreme value sampled from the originally identified population.

- It may be an accurate value that appears to be extreme with respect to the remaining values in the data set due to failure to obtain a representative sample. This may occur because an insufficient number of samples was collected to reflect the true variability in the population or possibly because biased sampling was conducted rather than *RANDOM* sampling of the population.

In practice, true outliers can be difficult to identify because rarely do we know the parameter values of the population from which our data were sampled. Generally, the parameters must be estimated from the data, thus introducing uncertainty to outlier analysis.

Statistical methods are available for identifying outliers, as presented in Section 2.1. However**, it is important to note that classification of an observation as an outlier does not automatically imply that the observation should be removed from the data set**. This is supported by Gilbert (1987) and EPA (1992c), among others. Outlier testing simply provides methods for quantitatively identifying observations that need to be investigated further and checked for possible errors. Often, outliers provide important information that should not be casually dismissed. As noted by Millard (1998), the hole in the ozone layer over Antarctica

could have been discovered earlier; however it was delayed as a result of "flagging" low-level outliers in the data (Stolarski et al., 1986).

Recommended treatment of outliers depends on the possible cause of the outlier and the context of the evaluation. Specific recommendations are provided in Section 2.2.

HOT SPOT Identification

Outlier testing may serve as a way to quantitatively assess for the presence of *HOT SPOTS*. *HOT SPOTS,* discussed in Section 2.2.1.1 of the tabbed section titled, "Sampling Strategies," are defined as "two or more adjacent sample locations in reasonably close proximity at which concentrations are sufficiently above criteria and surrounding locations (i.e., spatially correlated concentrations sufficiently above criteria) to indicate that they: 1) represent a different statistical population, or 2) pose a potential risk that should not be masked by a statistical analysis." Professional judgment may generally be used to determine whether the magnitude of concentrations and/or the number and proximity of spatially correlated samples above criteria are sufficient to classify an area as a *HOT SPOT*. Spatially correlated concentrations below criteria may also exist; however, these will not be classified as *HOT SPOTS* for the purpose of statistical analysis.

Because outlier testing provides a quantitative approach for evaluating whether elevated measurements are significantly different from a sampled population, it may be considered as a tool for identifying potential *HOT SPOTS* within an area such as an *EXPOSURE UNIT*. However, outlier testing does not take into consideration the spatial distribution of the data or the proximity of concentrations to criteria. For example, a result that is below criteria may be classified as an outlier simply because it is significantly higher than the remaining concentrations in the data set. This value would not represent a *HOT SPOT* as defined above since it is below criteria. Therefore, outlier testing may be *PROPOSED* as a tool, but it may not be used solely in identification of *HOT SPOTS*.

2.1 STATISTICAL METHODS FOR IDENTIFICATION OF OUTLIERS

Formal testing for outliers should be completed only if the presence of one or more outliers is suspected, as recommended by EPA (1992c). Many of the methods described in Chapter 1 of Statistical Methods serve as screening tools for identification of outliers. For example, outliers may be suspected if either a high coefficient of variation (Section 1.2.1) or a coefficient of skewness (Section 1.2.2) far from zero is observed, particularly if these conditions exist when calculated using both the raw and log-transformed data. Furthermore, potential outliers can be easily identified on graphs such as probability plots (Section 1.2.3) and box plots (Section 1.2.4). Since plots are often of greater utility than summary statistics for identifying potential outliers, graphical techniques are always recommended as outlier screening tools.

Once a potential outlier is identified (i.e., through visual inspection of tabulated data or use of other screening tools), formal testing should be completed before classifying the observation as an outlier. Three formal tests are provided for this purpose. In addition, an informal, iterative approach is described.

Type of Method	Method	Section
Graphical Technique	Probability Plots	2.1.1
Graphical Technique	Box Plots	2.1.2
Formal Test	Grubbs' Test (single outlier)	2.1.3
Formal Test	Dixon's Test (multiple outliers, n $\leq$ 25)	2.1.4
Formal Test	Rosner's Test (multiple outliers, n > 25)	2.1.5
Iterative Approach	Retesting with methods described in Chapter 1	2.1.6

It should be mentioned that each of the formal tests for outliers shown above assumes that the data under consideration are normally distributed. Formal outlier testing should be completed only in conjunction with tests for normality to ensure that this assumption is met. This is important since values that appear to be anomalous on the original scale may no longer appear inconsistent when transformed to the log scale. Consequently, the following recommendations are made:

- If a data set is concluded to be **normally distributed**, formal outlier testing should be completed on the raw (untransformed) data.

- If a data set is concluded to be **lognormally distributed**, formal outlier testing should be completed on the log-transformed (natural log) data.

The presence of outliers will sometimes cause a data set to fail tests for normality and lognormality. Therefore, if a data set is found to be **neither normal nor lognormal** and graphical techniques indicate the presence of a potential outlier, an iterative approach using methods described in Chapter 1 may be taken, as described in Section 2.1.6.

For data sets with 50% or more of the values below the detection limit, it is generally not possible to identify the statistical distribution of the data. Consequently, neither formal testing nor the iterative approach can be applied to the data. Therefore, it is necessary to identify outliers qualitatively using the graphical techniques shown above.

2.1.1 Probability Plots

As previously mentioned, one of the first steps in analyzing data is to determine the underlying statistical distribution. Chapter 1 outlines several methods for evaluating and identifying the underlying distribution of a data set. Probability plots provide an excellent tool not only for graphically assessing the distribution of a data set, but also for identifying potential outliers. See Procedure 1.3 for a description of how to construct a probability plot.

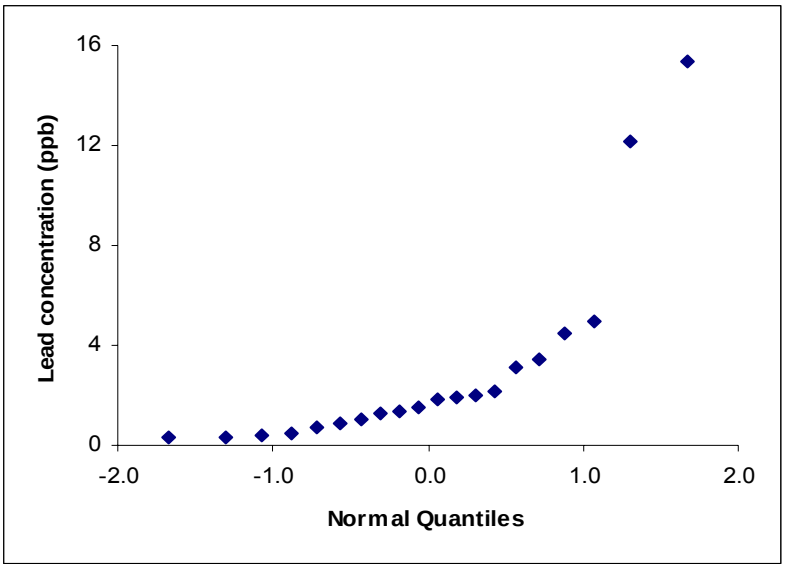


Interpretation: On a probability plot, potential outliers will appear as isolated points away from the other points. The other points may form a pattern, such as a line, with potential outliers deviating from this pattern. A probability plot can indicate whether and how many potential outliers there may be, but further testing should be

conducted before classifying the observations as outliers. In addition, some of the formal tests for outliers presented in this chapter (e.g., Rosner's Test) require an initial estimate of the number of outliers in the data set. A probability plot may be used to select this number.

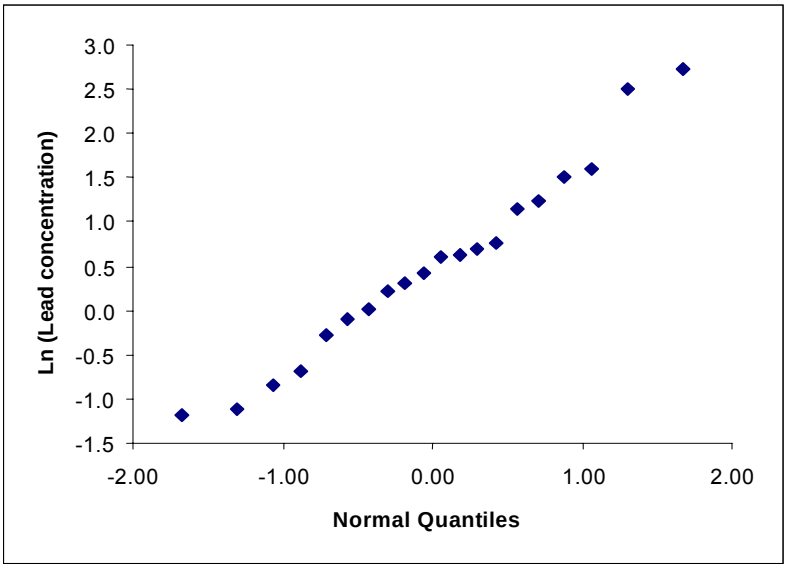
Example 2.1 Sample Probability Plots

Figure 2.1 Probability Plot of Lead Data



This probability plot, constructed using raw (untransformed) lead data, indicates the presence of two potential outliers. A probability plot of log-transformed (Ln) values should be reviewed before identifying these as potential

Figure 2.2 Probability Plot of Log-Transformed (Ln) Lead Data



This probability plot of log-transformed (Ln) lead concentrations does not clearly indicate the presence of potential outliers. Although the two highest values still stand out somewhat, they now fall relatively close to the straight line. Consequently, formal testing for outliers is not clearly necessary. Testing may be completed, however, based on professional judgment.

2.1.2 Box Plots

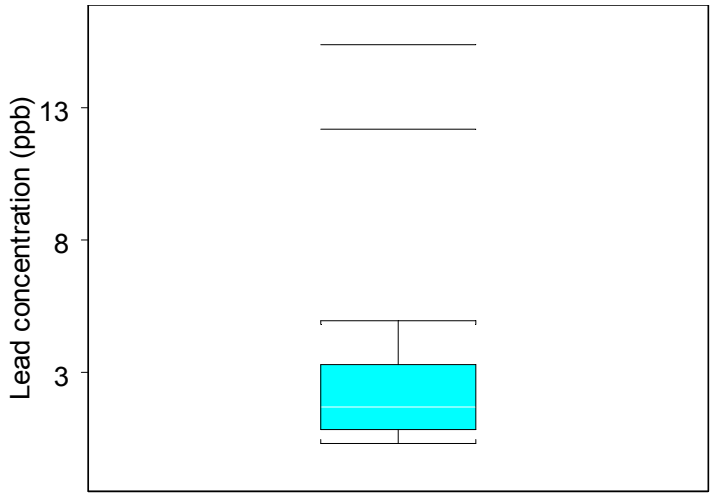
Box plots are another way to represent data graphically. Box plots were presented and described in Section 1.2.5.



Interpretation: On a box plot, potential outliers will appear as points (typically represented as asterisks or horizontal lines) beyond the whiskers of the plot. As with probability plots, box plots may be used to identify if potential outliers are present and, if so, how many. Formal testing should be completed before classifying these values as outliers.

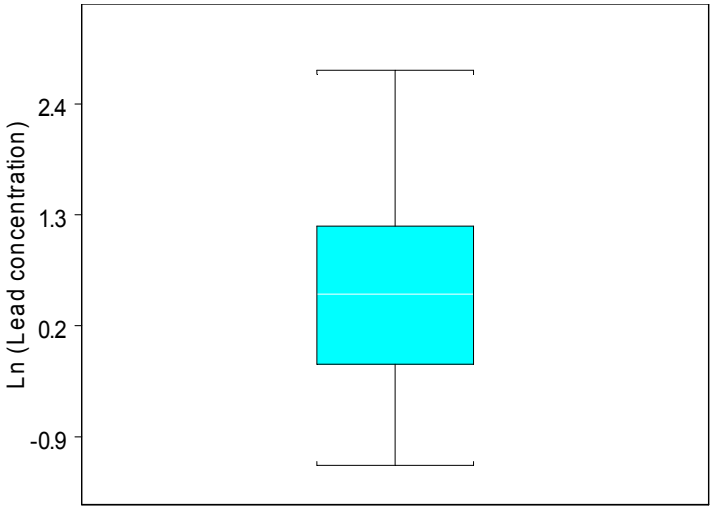
Example 2.2 Sample Box and Whisker Plots

Figure 2.3 Box Plot of Lead Data



This box plot, constructed using raw (untransformed) lead data, indicates the presence of two potential outliers. A box plot of log-transformed (Ln) values should be reviewed before identifying these as potential outliers.

Figure 2.4 Box Plot of Log-Transformed (Ln) Lead Data



This box plot of log-transformed (Ln) lead concentrations does not indicate the presence of any potential outliers. Consequently, formal testing for outliers may not be necessary.

2.1.3 Grubbs' Test

Grubbs' Test (Grubbs 1950, 1969) can be used to identify single outliers in most data sets with sample sizes ranging from small to relatively large ($3 < n < 100$). The test makes an assumption of normality, so the data set should first be evaluated for statistical distribution (Chapter 1). If the data are lognormally distributed, log-transform the data and conduct Grubbs' Test on the transformed values. Although Grubbs' Test can be used in an iterative fashion to evaluate whether there are multiple outliers, the procedure below describes only how to determine whether a single, large observation is an outlier. Other tests (e.g., Dixon's Test and Rosner's Test) should be used in cases where multiple outliers are suspected.

Procedure 2.1 Grubbs' Test for Single Outliers (3 < n < 100)

To test for outliers when the underlying distribution is normal, complete this procedure using the raw (untransformed) data, substituting 1/2 of the detection limit for nondetects up to 50% nondetect. To test for outliers when the underlying distribution is lognormal, first define y = ln(x) and use the y (log-transformed) values in place of the x values in the procedure below.

1. Calculate the sample mean ($\overline{x}$) and sample standard deviation (s) using all values, including the suspected outlier. (Equations 1.1 and 1.2 are reproduced below for convenience.)

$$\overline{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \overline{x})^2}{n-1}}$$

2. Denote the maximum value (the suspected outlier) by x_n and calculate T_G using the following equation:

$$T_G = (x_n - \overline{x}) / s \qquad \text{Equation 2.1}$$

3. Compare the value of T_G to the critical value T_α in Table 2.1 based on the sample size (n) and a 95% level of confidence (i.e., α=0.05).

4. If $T_G \geq T_\alpha$, conclude that the observation x_n is an outlier. Follow the guidelines presented in Section 2.2 regarding the treatment of outliers.



Statistical software packages may be used to obtain some of the calculated values shown above. Most of these packages provide the sample standard deviation (s), the sample mean ($\bar{x}$), and the maximum value together with other common summary statistics. Alternatively, Microsoft Excel can be used to obtain *s*, $\bar{x}$, and the maximum for use in Equation 1.3. The Excel functions that should be used to obtain these values, respectively, are:

=STDEV(data range)

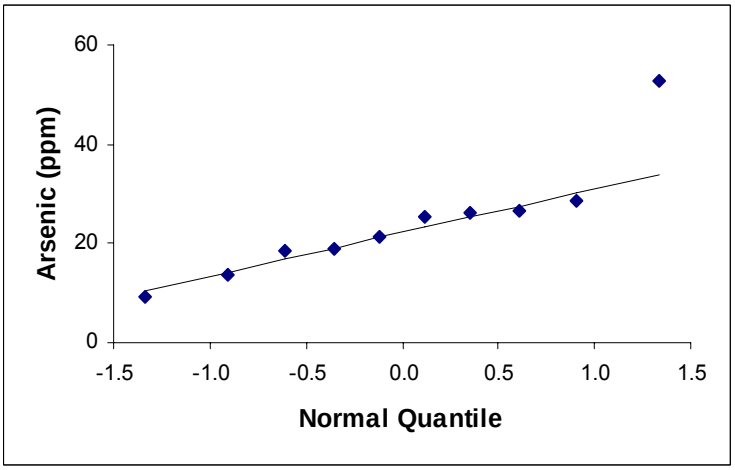
=AVERAGE(data range)

=MAX(data range)

Example 2.3 Sample Calculation of Grubbs' Test

At a hypothetical *FACILITY*, 10 samples for arsenic were collected. The measurements were 21.2, 26.0, 9.1, 28.7, 13.6, 52.6, 18.8, 25.5, 18.5, and 26.4 ppm. Suppose for this example that an evaluation as described in Chapter 1 indicated that the data were normally distributed, except for one potential outlier. Based on a normal probability plot (Figure 2.5), the largest observation (52.6 ppm) was suspected to be an outlier.

Figure 2.5 Probability Plot of Arsenic Data Set



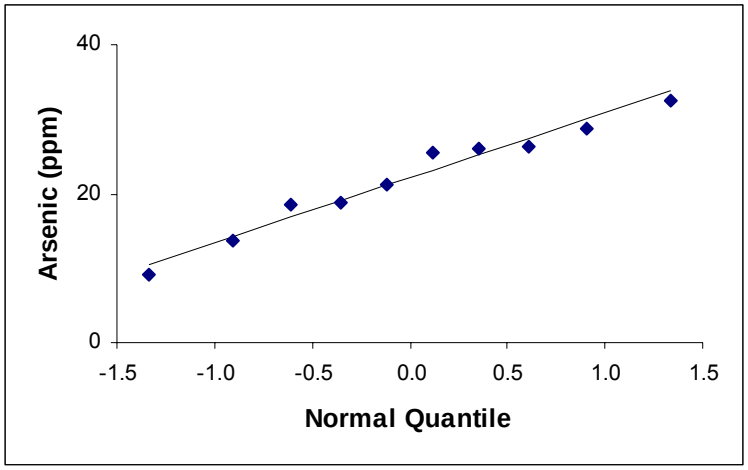
Spreadsheet Calculations for Grubbs' Test on the Arsenic Data Set

	A	B	C	D	E
1	Observation	Arsenic (ppm)			
2	1	9.1		**n:**	10
3	2	13.6			=COUNT(B2:B11)
4	3	18.5			
5	4	18.8		**Average:**	24.0
6	5	21.2			=AVERAGE(B2:B11)
7	6	25.5			
8	7	26.0		**Max:**	52.6
9	8	26.4			=MAX(B2:B11)
10	9	28.7			
11	10	52.6		**Std. Dev:**	11.8
12					=STDEV(B2:B11)
13					
14				**Grubb's T**	2.42
15					=(E8-E5)/E11

As shown above, the full data set was used to compute Grubbs' Test. The calculated value for T_G was 2.42 and the critical value T_α for a sample size of 10 at the α = 0.05 level is 2.176 (Table 2.1). Because $T_G > T_\alpha$ (2.42 > 2.176), we conclude that the 52.6 ppm observation is a statistical outlier.

Suppose that upon review of the data sheets, a data-entry error was found and the 52.6 ppm observation was actually measured as 32.6 ppm. After making this correction, we see that the probability plot of the raw data (Figure 2.6) now appears linear. Therefore, we would conclude that there are no outliers in the data set.

Figure 2.6 Probability Plot of Arsenic Data Set After Correcting Data-Entry Error



2.1.4 Dixon's Test

Dixon's Test (Dixon 1953) is used for identifying outliers in relatively small data sets ($n \leq 25$). Essentially, the test statistic is formed by a ratio, with the numerator representing the relative distance from the outlier to the next highest value and the denominator representing the spread of the data set (i.e., the range).

Dixon's Test is based on an assumption that the data are normally distributed. Therefore, the data set should first be evaluated for statistical distribution to make sure it conforms to this assumption (Chapter 1). If the data are lognormally distributed, log-transform the data and conduct Dixon's Test on the transformed values.

The test was initially developed for testing whether an individual observation is an outlier, but can be modified to accommodate testing for multiple outliers (Gibbons 1994). Consequently, if the data set is smaller than 25 and more than one outlier is suspected, Dixon's test is appropriate and can be used as follows:

Evaluate the *least extreme* observation first, temporarily excluding the more extreme observations from the data set. If the least extreme observation is identified as an outlier, then the more extreme observations can be classified as outliers as well. If the smallest potential outlier is not classified as such, then the next largest observation may be tested using the same procedure. This procedure, which is described in more detail in Procedure 2.2, may be continued until a set of outliers has been identified or until the test finds no outliers in the data set.

If more than one outlier is suspected and the sample size is greater than 25, Rosner's Test (Section 2.1.5) should be considered as an alternative to Dixon's Test. For more than 25 samples, Rosner's Test has the advantage of testing for both high and low outliers simultaneously. Dixon's Test can be used to test for high or low outliers, but no procedure has been established for testing for both high and low outliers simultaneously. DEQ recommends that Dixon's Test be used to test for high outliers with sample sizes less than 25. If sample sizes are less than 25 and low outliers or both high and low outliers are suspected, consultation with a professional statistician is advised.

Procedure 2.2 Dixon's Test for Single or Multiple Outliers (n < 25)

To test for outliers when the underlying distribution is normal, complete this procedure using the raw (untransformed) data, substituting 1/2 of the detection limit for nondetects up to 50% nondetects. To test for outliers when the underlying distribution is lognormal, first define y = ln(x) and use the y (log-transformed) values in place of the x values in the procedure below.

1. Order the data set from least to greatest and label the observations $x_{(1)}, x_{(2)}, ..., x_{(n)}$ where $x_{(1)}$ is the smallest observation and $x_{(n)}$ is the largest.

2. Based on the sample size (*n*), use the appropriate equation below to calculate the test statistic T_D:

n	Dixon's Test Statistic (T_D)	
3 - 7	$(x_{(n)} - x_{(n-1)}) / (x_{(n)} - x_{(1)})$	Equation 2.2
8 - 10	$(x_{(n)} - x_{(n-1)}) / (x_{(n)} - x_{(2)})$	Equation 2.3
11 - 13	$(x_{(n)} - x_{(n-2)}) / (x_{(n)} - x_{(2)})$	Equation 2.4
14 - 25	$(x_{(n)} - x_{(n-2)}) / (x_{(n)} - x_{(3)})$	Equation 2.5

3. Obtain the critical value for Dixon's test (T_α) based on the sample size (*n*) and a 95% level of confidence (i.e., α = 0.05) in Table 2.2.

4. Compare T_D to T_α. If $T_D > T_\alpha$, the value (and all potential outliers higher than this value) may be classified as outliers. Follow the recommendations for dealing with outliers (Section 2.2).



Microsoft Excel can be used to obtain each of the values for use in the above equations. The Excel functions that should be used to obtain the *k* th largest or smallest values, respectively, are:

=LARGE(data range,k)

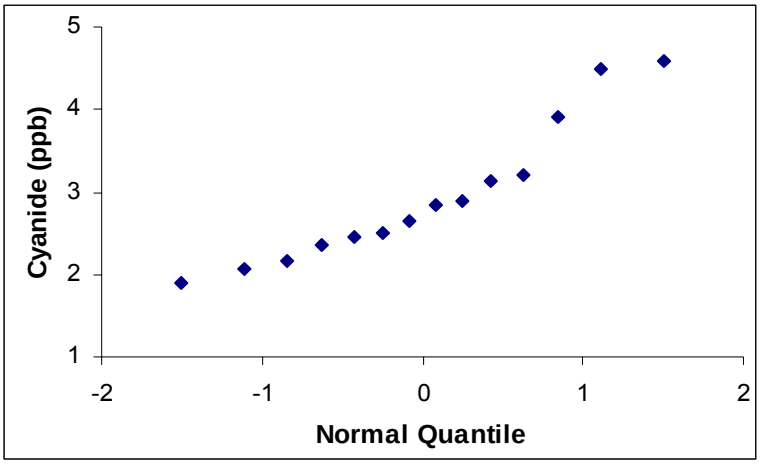
=SMALL(data range,k)

Where k denotes the *k* th largest or *k* th smallest value, respectively, in the data set.

Example 2.4 Sample Calculation of Dixon's Test

At a hypothetical *FACILITY*, 14 measurements for cyanide were collected. The values were 2.5, 4.5, 2.9, 1.9, 2.1, 3.9, 2.2, 2.4, 2.5, 4.6, 2.7, 2.8, 3.1, and 3.2 ppb. Suppose for this example that an evaluation as described in Chapter 1 indicated that the data were normally distributed, except for three potential outliers. Construction of a normal probability plot reveals that the three largest observations (3.9, 4.5, and 4.6 ppb) may be outliers (Figure 2.7).

Figure 2.7 Normal Probability Plot for Cyanide Data Set



Dixon's Test Calculations

	A	B	C	D	E	F
1	Observation	Cyanide				
2	1	1.9		Evaluating **3.9** :		
3	2	2.1			$x_{(12)}$:	3.9
4	3	2.2			$x_{(10)}$:	3.1
5	4	2.4			$x_{(2)}$:	2.1
6	5	2.5				
7	6	2.5			T_D:	0.444
8	7	2.7			= (3.9-3.1) / (3.9-2.1)	
9	8	2.8				
10	9	2.9			T (n=12):	0.546
11	10	3.1				
12	11	3.2		Evaluating **4.5**:		
13	12	**3.9**			$x_{(13)}$:	4.5
14	13	**4.5**			$x_{(11)}$:	3.2
15	14	**4.6**			$x_{(2)}$:	2.1
16						
17					T_D:	0.542
18					= (4.5-3.2) / (4.5-2.1)	
19						
20					T (n=13):	0.521

Because multiple outliers are suspected and the data set has less than 25 observations, Dixon's Test is appropriate. The least extreme potential outlier is evaluated first (3.9). The larger observations (4.5 and 4.6) are temporarily excluded from the data set, thus changing the sample size to 12 for the purposes of this test. With a sample size of 12, Equation 2.4 is used.

For n=12, the calculated value for T_D is 0.444 and the critical value for T based on a sample size of 12 is 0.546 (Table 2.2). Because 0.444 < 0.546, we conclude that 3.9 **is not an outlier**.

Next we move on to the 4.5 ppb observation. The 4.6 observation is temporarily excluded from the data set, changing the sample size to 13 for the purposes of this test. The calculated value for T_D is 0.542 (Figure 2.9) and the critical value for T based on a sample size of 13 is 0.521 (Table 2.2). Because 0.542 > 0.521, we conclude that the 4.5 ppb observation **is an outlier**. And because the 4.6 ppb observation is greater than the 4.5 ppb observation (which was just determined to be an outlier), we **consider both observations to be outliers**. Next we would follow the procedures outlined in Section 2.2 for dealing with these two outliers.

2.1.5 Rosner's Test

Rosner's Test (Rosner 1983) is an effective method for identifying outliers in moderate to large-sized data sets (i.e., n > 25). Potential outliers are tested in groups.

Similar to Grubbs' and Dixon's Tests, Rosner's Test assumes that the sampled population is normally distributed. Therefore, the data set should first be evaluated for statistical distribution to make sure it conforms to this assumption (Chapter 1). If the data are lognormally distributed, log-transform the data and conduct Rosner's Test on the transformed values.

Before completing Rosner's Test, the total number of potential outliers (k) must be identified. Probability plots, box plots, or a visual inspection of the tabulated data should be completed to screen first for potential outliers.

Rosner's Test procedure is iterative. As described in Procedure 2.3, the mean, standard deviation and maximum values are calculated first with the entire data set and again excluding potential outliers one by one, from largest to smallest, until all potential outliers have been removed. Then the first test statistic is calculated to test whether all k values are outliers. If the result is significant, all k observations are classified as outliers. If not significant, the group of possible outliers under evaluation is reduced by one (i.e., the smallest potential outlier is placed back in the data set) and the test statistic is recalculated considering the remaining k - 1 possible outliers. This process is repeated until a group of outliers is identified or until the test finds no outliers in the data set.

Procedure 2.3 Rosner's Test for Multiple Outliers (n > 25)

To test for outliers when the underlying distribution is normal, complete this procedure using the raw (untransformed) data, substituting 1/2 of the detection for nondetects up to 50% nondetect. To test for outliers when the underlying distribution is lognormal, first define y = ln(x) and use the y (log-transformed) values in place of the x values in the procedure below.

1. Order the data set from smallest to largest and denote the values as $x_{(1)}, x_{(2)}, \ldots x_{(n)}$. From plots or examination of the tabulated data, identify the number (*k*) of possible outliers.

2. Set *i* = 0 and use the following formulas

$$\bar{x}^{(i)} = (x_1 + x_2 + \ldots x_{n-i})/(n-i) \qquad \text{Equation 2.6}$$

$$s^{(i)} = \sqrt{\frac{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \ldots + (x_{n-i} - \bar{x})^2}{n-i}} \qquad \text{Equation 2.7}$$

Calculate the sample mean $(\bar{x})$ and sample standard deviation (s) for the full data set (i.e., when *i* = 0, the full data set is included in the above equations). Denote these values as $\bar{x}^{(0)}$ and $s^{(0)}$. Determine the value of the measurement furthest from $\bar{x}^{(0)}$ and denote it as $y^{(0)}$.

3. Remove the observation $y^{(0)}$ from the data set and recalculate the mean and standard deviation, denoting them as $\bar{x}^{(1)}$ and $s^{(1)}$ (i.e., set *i* = 1). Determine the value of the measurement furthest from $\bar{x}^{(1)}$ and denote it as $y^{(1)}$.

4. Remove the observation $y^{(1)}$ from the data set and recalculate the mean and standard deviation, denoting them as $\bar{x}^{(2)}$ and $s^{(2)}$ (i.e., set *i* = 2). Note that *i* refers to the number of observations that have been removed from the data set.

5. Repeat steps 3 and 4 until k potential outliers have been removed. This should provide a set of results similar to:

$$\left[\bar{x}^{(0)}, s^{(0)}, y^{(0)}\right], \left[\bar{x}^{(1)}, s^{(1)}, y^{(1)}\right], \ldots, \left[\bar{x}^{(k-1)}, s^{(k-1)}, y^{(k-1)}\right]$$

6. Evaluate the test for all k possible outliers first. To test for k outliers, compute the test statistic:

$$R_k = \left| y^{(k-1)} - \bar{x}^{(k-1)} \right| \Big/ s^{(k-1)} \qquad \text{Equation 2.8}$$

(Continued on next page)

Procedure 2.3 Rosner's Test (continued)

7. Obtain the critical value (R_α) from Table 2.3 given the sample size (n) and a 95% level of confidence (α = 0.05). If $R_k > R_\alpha$, conclude that there are k outliers. If not, repeat the procedure testing for $k-1$ outliers. Continue in this fashion until a group of outliers has been identified or until the test finds no outliers in the data set.

8. If one or more outliers are identified, see Section 2.2 regarding treatment of outliers.



In most cases, it should not be necessary to calculate Equations 2.6 through 2.8 by hand. Most statistical software packages provide the sample standard deviation (s) and the sample mean ($\bar{x}$) together with other common summary statistics. Alternatively, Microsoft Excel can be used to obtain s and $\bar{x}$ for use in Equation 2.8. The Excel functions that should be used to obtain these values, respectively, are:

=STDEV(data range)

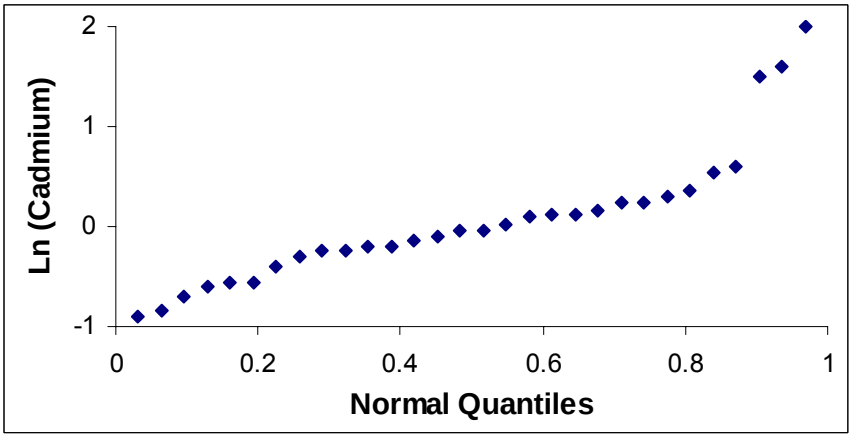
=AVERAGE(data range)

Where the data range should be modified as necessary for each iteration described above.

Example 2.5 Sample Calculation of Rosner's Test

Suppose that 30 observations for cadmium are collected at a site. For the purpose of this example, further suppose that the data were concluded to be lognromally distributed using the methods described in Chapter 1. Based on a probability plot of the log-transformed (Ln) data, the data appeared to contain three possible outliers (Figure 2.10).

Figure 2.8 Probability Plot of Log-Transformed (Ln) Cadmium



Calculations for Rosner's Test With the Cadmium Data Set

	A	B	C	D	E	F	G	H	I	J
1	Observation	Ln (Cadmium)								
2	1	-0.90		i	n-i	$\bar{y}^{(i)}$	$s_y^{(i)}$	$y^{(i)}$	R	$R_{crit.}$
3	2	-0.85		0	30	0.06	0.68	2.00	2.87	2.91
4	3	-0.70		1	29	0.00	0.58	1.60	2.77	2.89
5	4	-0.59		2	28	-0.06	0.50	1.50	3.13	2.88
6	5	-0.57								
7	6	-0.57				=AVERAGE(B2:B31)	=STDEV(B2:B31)	=MAX(B2:B31)	=ABS(H3-F3)/G3	
8	7	-0.40				=AVERAGE(B2:B30)	=STDEV(B2:B30)	=MAX(B2:B30)	=ABS(H4-F4)/G4	
9	8	-0.29				=AVERAGE(B2:B29)	=STDEV(B2:B29)	=MAX(B2:B29)	=ABS(H5-F5)/G5	
10	9	-0.23								
11	10	-0.23								
12	11	-0.20								
13	12	-0.19								
14	13	-0.13								
15	14	-0.10								
16	15	-0.03								
17	16	-0.03								
18	17	0.03								
19	18	0.10								
20	19	0.11								
21	20	0.13								
22	21	0.16								
23	22	0.25								
24	23	0.25								
25	24	0.30								
26	25	0.36								
27	26	0.55								
28	27	0.60								
29	28	1.50								
30	29	1.60								
31	30	2.00								

The three highest observations were evaluated using Rosner's Test. By equation 2.8, to test for three outliers, we must calculate R_3. The result of this calculation was 3.13 and the critical value for R (with n = 30 and i = 3) was 2.88 (Table 2.3). Because 3.13 > 2.88, we conclude that there are three outliers in the cadmium data set (1.5, 1.6, and 2.0).

2.1.6 Informal Iterative Approach to Outlier Testing When Data Set is Not Normal or Lognormal

As previously noted, the presence of outliers will sometimes cause a data set to fail tests for normality and lognormality. If a data set is found to be neither normal nor lognormal and graphical techniques indicate the presence of a potential outlier, an iterative approach using methods described in Chapter 1 may be taken, as described below.

- If one outlier is suspected, remove the potential outlier and reevaluate for normality and lognormality using the remaining observations and the methods described in Section 1. If the data pass a test for normality or lognormality without the suspected outlier, classify the anomalous value as an outlier.

- If multiple outliers are suspected, exclude them one by one and repeat the above step until the data pass a test of normality or lognormality or all of the potential outliers have been removed.

2.1.7 Walsh's Test

The formal outlier tests presented in this chapter have relied on an assumption of normality. Walsh's Test (Walsh 1958) provides a nonparametric alternative for evaluating potential outliers. Unfortunately, rather large sample sizes are required. For example, $n > 60$ is necessary to obtain a significance level of $\alpha = 0.10$ and $n > 220$ to obtain a significance level of $\alpha = 0.05$. Because of the large sample sizes necessary, it is doubtful that Walsh's Test can be applied to most environmental data sets and therefore a detailed procedure for conducting the test is not provided. However, if enough samples have been collected and the distribution appears to be neither normal nor lognormal, then Walsh's Test may be appropriate and can be *PROPOSED* for review by the DEQ statistician.

2.1.8 Evaluating for Outliers when Data Contain >50% Nondetects

As previously stated, for data sets with > 50% nondetects, it is generally not possible to identify the statistical distribution of the data (Helsel, 1990). Consequently, neither formal testing nor the iterative approach can be applied to the data. In this case, it will be necessary to evaluate for and identify outliers qualitatively using the graphical techniques described in Sections 2.1.1 and 2.1.2.

2.2 TREATMENT OF OUTLIERS

All values classified as outliers through formal testing (Section 2.1) should be thoroughly investigated before deciding how to treat them. The "chain of custody" records for the outlier should be reviewed as a check of the steps of the sampling and analysis up to this point. Each of the possible causes for outliers described in the introductory portion of this chapter should be considered.

Once all outliers have been investigated, one of the following actions should be taken:

1. If a transcription error is found and the correct value can be determined, replace the outlier with the correct value and conduct statistical analyses with the corrected value. The procedures described in Chapters 1 and 2 should be completed again with the revised data set.

2. If the observation can be proven erroneous, but the correct value cannot be determined, the outlier can be deleted and subsequent analyses conducted on the reduced data set. If a value is deleted from the data set, this fact must be reported with the statistical results.

3. If no error in the value can be found, the outlier should be regarded as a true, but extreme, observation. If this is the case, one of the following courses of action should be taken, depending on the general location of the sample containing the outlier.

   - ***FACILITY-SPECIFIC BACKGROUND*** **samples collected off of the property of interest:** If samples from the data set of interest were collected from off-site locations for the purpose of determining *FACILITY-SPECIFIC BACKGROUND* concentrations *and* the

outlier is not believed to represent naturally occurring *BACKGROUND* concentrations, the outlying value should be removed from the data set and documented as such. If the value is believed to be representative of *BACKGROUND* conditions, the value should be retained in the data set. Alternate statistical methods and/or additional sampling may be necessary.

- ***FACILITY-SPECIFIC BACKGROUND* samples collected on the property of interest:** If *FACILITY-SPECIFIC BACKGROUND* samples were collected from locations on the property of interest and the outlier is not believed to represent naturally occurring *BACKGROUND* concentrations, the outlying value may represent a previously unidentified area of contamination. The outlying result should be compared to the appropriate Part 201 criteria to determine if it represents a *FACILITY*. Additional characterization may be necessary in this area.

- ***FACILITY* samples:** If samples from the data set of interest were collected from locations within a *FACILITY*, the outlying value may represent a previously unidentified *HOT SPOT* if the concentration is sufficiently above criteria. Additional characterization may be necessary to determine if a *HOT SPOT* exists.

Table 2.1 Grubbs' Test Critical Values (T_α, α = 0.05). From Grubbs and Beck, 1972.

n	T_α	n	T_α	n	T_α
3	1.153	51	2.964	101	3.210
4	1.463	52	2.971	102	3.214
5	1.672	53	2.978	103	3.217
6	1.822	54	2.986	104	3.220
7	1.938	55	2.992	105	3.224
8	2.032	56	3.000	106	3.227
9	2.110	57	3.006	107	3.230
10	2.176	58	3.013	108	3.233
11	2.234	59	3.019	109	3.236
12	2.285	60	3.025	110	3.239
13	2.331	61	3.032	111	3.242
14	2.371	62	3.037	112	3.245
15	2.409	63	3.044	113	3.248
16	2.443	64	3.049	114	3.251
17	2.475	65	3.055	115	3.254
18	2.504	66	3.061	116	3.257
19	2.532	67	3.066	117	3.259
20	2.557	68	3.071	118	3.262
21	2.580	69	3.076	119	3.265
22	2.603	70	3.082	120	3.267
23	2.624	71	3.087	121	3.270
24	2.644	72	3.092	122	3.274
25	2.663	73	3.098	123	3.276
26	2.681	74	3.102	124	3.279
27	2.698	75	3.107	125	3.281
28	2.714	76	3.111	126	3.284
29	2.730	77	3.117	127	3.286
30	2.745	78	3.121	128	3.289
31	2.759	79	3.125	129	3.291
32	2.773	80	3.130	130	3.294
33	2.786	81	3.134	131	3.296
34	2.799	82	3.139	132	3.298
35	2.811	83	3.143	133	3.302
36	2.823	84	3.147	134	3.304
37	2.835	85	3.151	135	3.306
38	2.846	86	3.155	136	3.309
39	2.857	87	3.160	137	3.311
40	2.866	88	3.163	138	3.313
41	2.877	89	3.167	139	3.315
42	2.887	90	3.171	140	3.318
43	2.896	91	3.174	141	3.320
44	2.905	92	3.179	142	3.322
45	2.914	93	3.182	143	3.324
46	2.923	94	3.186	144	3.326
47	2.931	95	3.189	145	3.328
48	2.940	96	3.193	146	3.331
49	2.948	97	3.196	147	3.334
50	2.956	98	3.201		
		99	3.204		
		100	3.207		

Table 2.2 Critical Values for Dixon's Test (T_α, α = 0.05). From Dixon, 1953.

n	T
3	0.941
4	0.765
5	0.642
6	0.560
7	0.507
8	0.554
9	0.512
10	0.477
11	0.576
12	0.546
13	0.521
14	0.546
15	0.525
16	0.507
17	0.490
18	0.475
19	0.462
20	0.450
21	0.440
22	0.430
23	0.421
24	0.413
25	0.406

Table 2.3 Rosner's Test Critical Values (R_α, α = 0.05 for Various Levels of *n* and *k*). From Rosner, 1983.

n	k	Rα	n	k	Rα	n	k	Rα
25	1	2.82	35	1	2.98	45	1	3.09
	2	2.80		2	2.97		2	3.08
	3	2.78		3	2.95		3	3.07
	4	2.76		4	2.94		4	3.06
	5	2.73		5	2.92		5	3.05
	10	2.59		10	2.84		10	2.99
26	1	2.84	36	1	2.99	46	1	3.09
	2	2.82		2	2.98		2	3.09
	3	2.80		3	2.97		3	3.08
	4	2.78		4	2.95		4	3.07
	5	2.76		5	2.94		5	3.06
	10	2.62		10	2.86		10	3.00
27	1	2.86	37	1	3.00	47	1	3.10
	2	2.84		2	2.99		2	3.09
	3	2.82		3	2.98		3	3.09
	4	2.80		4	2.97		4	3.08
	5	2.78		5	2.95		5	3.07
	10	2.65		10	2.88		10	3.01
28	1	2.88	38	1	3.01	48	1	3.11
	2	2.86		2	3.00		2	3.10
	3	2.84		3	2.99		3	3.09
	4	2.82		4	2.98		4	3.09
	5	2.80		5	2.97		5	3.08
	10	2.68		10	2.91		10	3.03
29	1	2.89	39	1	3.03	49	1	3.12
	2	2.88		2	3.01		2	3.11
	3	2.86		3	3.00		3	3.10
	4	2.84		4	2.99		4	3.09
	5	2.82		5	2.98		5	3.09
	10	2.71		10	2.91		10	3.04
30	1	2.91	40	1	3.04	50	1	3.13
	2	2.89		2	3.03		2	3.12
	3	2.88		3	3.01		3	3.11
	4	2.86		4	3.00		4	3.10
	5	2.84		5	2.99		5	3.09
	10	2.73		10	2.92		10	3.05
31	1	2.92	41	1	3.05	60	1	3.20
	2	2.91		2	3.04		2	3.19
	3	2.89		3	3.03		3	3.19
	4	2.88		4	3.01		4	3.18
	5	2.86		5	3.00		5	3.17
	10	2.76		10	2.94		10	3.14
32	1	2.94	42	1	3.06	70	1	3.26
	2	2.92		2	3.05		2	3.25
	3	2.91		3	3.04		3	3.25
	4	2.89		4	3.03		4	3.24
	5	2.88		5	3.01		5	3.24
	10	2.78		10	2.95		10	3.21
33	1	2.95	43	1	3.07	80	1	3.31
	2	2.94		2	3.06		2	3.30
	3	2.92		3	3.05		3	3.30
	4	2.91		4	3.04		4	3.29
	5	2.89		5	3.03		5	3.29
	10	2.80		10	2.97		10	3.26
34	1	2.97	44	1	3.08	100	1	3.38
	2	2.95		2	3.07		2	3.38
	3	2.94		3	3.06		3	3.38
	4	2.92		4	3.05		4	3.37
	5	2.91		5	3.04		5	3.37
	10	2.82		10	2.98		10	3.35

CHAPTER 3: CALCULATION OF A 95% UPPER CONFIDENCE LIMIT (UCL) FOR THE MEAN CONCENTRATION

A goal of sampling environmental media is often to identify characteristics and/or draw conclusions about a defined population. An example of a typical population of interest under the Part 201 program would be concentrations of a hazardous substance in surface soil within a 1/4 acre *EXPOSURE UNIT*. One characteristic of the population that is useful to identify is the mean concentration. The mean, which is a measure of centrality, represents an average value. Other measures of centrality include the median (i.e., the middle value) and the mode (i.e., the most frequently occurring value). The mean and the median are more commonly used than the mode in environmental applications.

It is the MDEQ's policy that a mean rather than a median or other measure of centrality be used to estimate concentrations of hazardous substances for the purpose of comparison to Part 201 criteria. In terms of exposure to hazardous substances, the mean provides the best representation of average exposure levels at a *FACILITY* because it incorporates the magnitude of all observations. This is consistent with EPA guidance, which recommends for purposes of risk assessment that the mean concentration be used to estimate risks through exposure to a hazardous substance (EPA, 1992a). **Due to uncertainty in estimating the true mean concentration based on sample data, a UCL for the mean must generally be used to compare concentration data to Part 201 criteria, as described below.**

The true mean, also referred to as the population mean, is typically estimated by collecting data and using these data to calculate a sample mean. A sample mean is an example of a point estimate. It provides a single value to estimate the population mean; it does not represent the variability or uncertainty associated with the estimate. Confidence intervals around the sample mean are used to represent the range of uncertainty or variability associated with this estimate of the mean.

Confidence intervals can also be used to conduct a statistical test of the mean. For example, a UCL for the mean can be compared to a fixed value, such as a Part 201 criterion, to test whether a sample mean concentration is below the Part 201 criterion. This corresponds directly with EPA's recommendation that a UCL for the mean be used to estimate a reasonable maximum exposure (RME) concentration for Superfund risk assessments (EPA, 1992a). The RME "is intended to account for both uncertainty in the hazardous substance concentration and variability in exposure parameters (e.g., exposure frequency, averaging time)."

Use of a UCL for the mean to compare *FACILITY* data to Part 201 criteria corresponds to the following null and alternative hypotheses:

Hypothesis 1

H_o: The mean hazardous substance concentration in a given *EXPOSURE UNIT* is greater than or equal to the Part 201 criterion

H_a: The mean hazardous substance concentration in a given *EXPOSURE UNIT* is less than the Part 201 criterion

The null hypothesis (H_o) represents the condition that is assumed to be true. The alternative hypothesis (H_a), also known as the research hypothesis (H_R), is the converse of the null hypothesis. The alternative hypothesis will be concluded only if the sample data provide sufficient evidence that the null hypothesis is incorrect.

Practically speaking, the baseline assumption stated above in Hypothesis 1 is that the mean concentration is at or above its respective criterion unless the sample data provide sufficient evidence to conclude otherwise. Use of this baseline assumption is consistent with EPA's recommendations in the context of their cleanup programs (e.g., the Superfund program and RCRA Corrective Action) as described in many EPA statistical guidance documents (1989a, 1989b, 1992a, 1992b, 1993, 1996a, 1996b, 1999).

Further, EPA (1992b) recommends:

> *Make an assumption about the concentrations which you would like to disprove (e.g., the average population measure of a contaminant is greater than the cleanup standard of 2.0 ppm). This cleanup standard represents your initial or null hypothesis about the current situation.*

By setting the null hypothesis as something one wants to disprove, the motivation is to conduct a proper and rigorous statistical analysis in order to disprove this condition. In other words, be skeptical that concentrations meet criteria until evidence proves otherwise. Conversely, if the null hypothesis is set as something one wants to prove (e.g., hazardous substance concentrations are below Part 201 criteria), there is no motivation to obtain sufficient data or to utilize statistical rigor to disprove this assumption.

When calculating a UCL for the mean for the purpose of comparing *FACILITY* data to Part 201 criteria, a significance level of $\alpha = 0.05$ should be used. A significance level of $\alpha = 0.10$ may be used for the purpose of waste characterization (SW-846 Chapter 9; EPA 1986). See the tabbed section titled, "Waste Characterization" for further detail.

3.1 STEPS FOR CALCULATING AN UPPER CONFIDENCE LIMIT FOR THE MEAN

A minimum of nine *RANDOMLY* located samples per *EXPOSURE UNIT* is required if statistics are to be used to compare *FACILITY* data to Part 201 criteria. (For waste characterization purposes, a minimum of nine *RANDOM* samples is required if statistics are to be used to compare characterization data to regulatory thresholds.) This minimum number is necessary to evaluate the underlying statistical distribution of the data set, as described in Chapter 1. The necessity of evaluating the distribution of the data set is discussed below and described in detail in Chapter 1.

The following methods for calculating UCLs for the mean are presented or discussed in this chapter:

Method	Section
Student's t (recommended for normally distributed data)	3.1.1
Land's Method (recommended for lognormally distributed data)	3.1.2

Alternate methods for data sets which are neither normal nor lognormal (may be *PROPOSED* on a case-by-case basis)	3.1.3

Assumptions

Each of the statistical methods described in this chapter was developed based on certain underlying assumptions. For example, all of the methods described in this chapter require an assumption that the data are statistically independent (i.e., there are no trends in the data and obtained through *RANDOM* sampling) and representative of a single statistical distribution. Data should therefore be plotted on a map to identify spatial trends and or *HOT SPOTS* before conducting a statistical analysis. Furthermore, Statistical Guidesheets must be referred to for key considerations on the selection of an appropriate data set for development of a *REPRESENTATIVE CONCENTRATION*. Additional considerations and recommendations are presented in the tabbed section titled, "Sampling Strategies." (See Sections 1.2 and 2.2 on *FACILITY* Characterization and Section 2.4 on demonstrating compliance with Part 201 criteria using statistics.)

A second assumption required by many statistical methods is that the data were obtained from a specified underlying statistical distribution. Statistical methods requiring knowledge of the statistical distribution are called parametric methods. The method for constructing a UCL for the mean presented in Section 3.1.1 is based on an assumption that the data follow a normal distribution. Section 3.1.2 presents a method that was designed for data assumed to be lognormally distributed (Gilbert, 1987; EPA, 1992a).

Steps for Constructing a UCL for the Mean

The following procedure describes the selection of an appropriate method for calculating a UCL for the mean:

1) Determine the percent of data below the detection limit (e.g., a data set with nine samples, three of which are below the detection limit, contains 33% nondetects).

2) For data sets with < 50% nondetects, evaluate and identify the underlying statistical distribution of the data using the methods presented in Chapter 1. This step is not required for data sets with ≥ 50% nondetects, although the methods presented in Chapter 1 may still provide some insight into the data to the extent that detectable concentrations are contained in the data set.

3) All data sets should be evaluated for outliers as described in Chapter 2 whenever *FACILITY* data are being statistically compared to Part 201 criteria. Many of the methods for calculating UCLs for the mean concentration presented in this chapter are sensitive to outliers. As noted in Chapter 2, formal testing for outliers is recommended only if initial screening of the data (i.e., a review of tabulated data and/or plots) indicates the presence of one or more potential outliers. For data sets with ≥ 50% nondetects, the data should be qualitatively evaluated for outliers using the graphical techniques presented in Chapter 2.

4) Select the appropriate formula for calculation of a 95% UCL for the mean:
   - Data sets with < 50% nondetects that are approximately normal: see Section 3.1.1.
   - Data sets with < 50% nondetects that are approximately lognormal: see Section 3.1.2.

- Data sets with ≥ 50% nondetects and/or are neither normal nor lognormal: see Section 3.1.3.

Unfortunately, widely accepted methods are not available to calculate UCLs for the mean of data sets that contain ≥ 50% nondetects and/or are neither normal nor lognormal. Consequently, alternative methods for statistically comparing *FACILITY* data to Part 201 criteria must be *PROPOSED* if departmental approval of a response activity is being sought. Section 3.1.3 describes some alternative methods that may be considered, including nonparametric (i.e., distribution-free methods) and large sample approximations.

The importance of evaluating the underlying assumptions for each method can not be over-stated if accurate conclusions are to be drawn. Therefore, it is necessary to identify the underlying assumptions of each method up front and evaluate these assumptions as described above before calculating UCLs for the mean concentration for comparison to Part 201 criteria.

3.1.1 UCL for the Mean of a Normally Distributed *RANDOM* Variable (Student's t)

When a data set is normally distributed, a UCL for the mean may be calculated based on the Student's t distribution for comparison to Part 201 criteria. Procedure 3.1 describes the calculation of a UCL for the mean of a normal distribution using the Student's t distribution.

Assumptions

The assumption underlying this method is that the data set is approximately normal in its distribution. Although this method is somewhat robust to slight deviations from normality, this assumption should be evaluated using the methods described in Chapter 1.

Example 3.1 Sample Calculation of a Student's t 95% Upper Confidence Limit for the Mean of a Normally Distributed *RANDOM* Variable

Suppose that we have 10 observations of lead concentrations and they are 4.4, 2.4, 5.5, 7.6, 7.4, 8.5, 0.6, 4.5, 7.2, and 2.8 ppb. An evaluation of the data as described in Chapter 1 indicates that the data set is approximately normal. The calculations necessary to calculate a 95% UCL for the mean are presented in Figure 3.1 using Microsoft Excel. For this data set, the 95% UCL for the mean is 6.59 ppb.

Figure 3.1 Spreadsheet Calculations for a 95% UCL for the Mean

	A	B	C	D	E
1	Observation	Lead			
2	1	4.4		n:	10
3	2	2.4			=COUNT(B2:B11)
4	3	5.5			
5	4	7.6		$\bar{x}$:	5.09
6	5	7.4			=AVERAGE(B2:B11)
7	6	8.5			
8	7	0.6		s:	2.58
9	8	4.5			=STDEV(B2:B11)
10	9	7.2			
11	10	2.8		t (0.95, 9):	1.83
12					=TINV(0.1,9)
13					
14				95% UCL:	6.59
15				= E5 + E8 * E11 / SQRT(10)	

Procedure 3.1 Student's t Upper (1-α)% Confidence Limit for the Mean of a Normally Distributed *RANDOM* Variable

The Student's t method for calculating a UCL for the mean relies on having normal or nearly normal data. First evaluate the statistical distribution of the data using the methods described in Chapter 1. Outlier testing (Chapter 2) should be completed if suspect values are identified based on review of the data and/or graphs described in Chapter 1.

1. Calculate the sample mean ($\bar{x}$) and the sample standard deviation (*s*). (Equations 1.1 and 1.2 are reproduced below for convenience.)

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}}$$

where x_i represents the *i* th observed value, *s* represents the sample standard deviation, and $\bar{x}$ represents the sample mean and *n* is the number of samples in the data set. Substitute ½ of the detection limit for nondetects up to 50% nondetects. Additional options for handling nondetects are described in Chapter 5.

2. Using Table 3.1, look up the Student's t value for a (1-α)% level of confidence (α = 0.05 for Part 201 applications; α = 0.10 may be considered for waste characterization) and *n-1* degrees of freedom. This value is denoted $t_{1-\alpha,n-1}$.

3. Calculate the one-sided (1-α)% UCL for the mean as follows:

$$UCL_{1-\alpha} = \bar{x} + t_{1-\alpha,n-1}\frac{s}{\sqrt{n}} \qquad \text{Equation 3.1}$$



In most cases, it should not be necessary to calculate the above equations by hand. Most statistical software packages provide the sample standard deviation (s) and the sample mean ($\bar{x}$) with other common summary statistics. Alternatively, Microsoft Excel can be used to obtain *s*, $\bar{x}$, and the tabled value of $t_{1-\alpha,n-1}$. The Excel functions that can be used to obtain these values, respectively, are:

=STDEV(data range)
=AVERAGE(data range)
=TINV(2α,*n* -1)

Note that a value of 2 times α (e.g., 0.10 for α = 0.05 or 0.20 for α = 0.10 is used in the =TINV() function rather than α. This is because Excel automatically provides t-values for two-sided intervals, rather than one-sided intervals. Using α = 0.1 in this function will yield the correct t-value for a one-sided 95% UCL for the mean. This may be necessary for many of the statistical software packages as well.



Interpretation: If $UCL_{1-\alpha}$ > criterion, conclude that the mean concentration is above the criterion. If $UCL_{1-\alpha}$ < criterion, conclude that the mean concentration is below the criterion.

Note that a more correct statement of the interpretation would be to conclude that the mean is at or above the criterion if the UCL for the mean is greater than or equal to the criterion. However, because the data being evaluated are measured on a continuous scale, the probability of obtaining a UCL for the mean that is exactly equal to a given criterion is essentially zero. Therefore, the interpretation stated above will be relied upon for these comparisons.

3.1.2 UCL on the Mean of a Lognormally Distributed *RANDOM* Variable (Land's Method)

In cases where the data are lognormally distributed, Land's method can be used to calculate a UCL for the mean (Land, 1971; Gilbert, 1987; EPA, 1992a). Procedure 3.2 describes the calculation of a (1-α)% UCL for the mean using Land's method.

Land's method is sensitive to departures from lognormality. For example, a right-skewed data set (i.e., asymmetric with a long right tail) may be concluded to be lognormal based on an analysis as described in Chapter 1. However, the data set may be more highly skewed than a true lognormal distribution and/or contain one or more outliers. The resulting UCL for the mean may be inappropriately high. This is more likely to be the case when the sample size is small and/or highly variable. If this occurs, consider increasing the sample size until a more reasonable value is obtained. Alternative statistical methods may also be *PROPOSED*. Suggested methods for consideration include a method described by Parkin, et. al. (1990) or the methods described in Section 3.1.3.

Assumptions

Land's method is based on an assumption that the sampled population is lognormally distributed. Even slight deviations from lognormality may result in unreasonably high UCLs for the mean. The methods outlined in Section 1 should be used to evaluate this assumption.

Procedure 3.2 Land's Method for Calculating a (1-α)% UCL for the Mean of a Lognormally Distributed *RANDOM* Variable

Land's method is intended for lognormally distributed data only. Use Chapter 1 to ensure that this is the case before using Land's method. Outlier testing (Chapter 2) should be completed if suspect values are identified based on review of the data and/or graphs described in Chapter 1.

1. For nondetects, substitute 1/2 of the detection limit up to 50% nondetects. (See Chapter 5 for additional options for handling nondetects.) Then calculate the natural logarithm (Ln) of each observation in the data set (i.e., log-transform the data set). Define y = ln(x).

2. Calculate the mean $(\bar{y})$ and standard deviation (s_y) of the log-transformed data set using the y values in place of the x values in Equations 1.1 and 1.2. (Equations 1.1 and 1.2 are reproduced below for convenience.)

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}}$$

3. Look up the value for $H_{1-\alpha}$ in Table 3.2 for α = 0.05 (Part 201 applications) or Table 3.3 for α = 0.10 (for some waste characterization applications). This value is dependent upon the sample size (*n*) and the standard deviation of the log-transformed data (s_y). If the correct number of samples and standard deviation are not represented on the table, it will be necessary to interpolate between adjacent points. It may be necessary to interpolate in both directions. The details of a double linear interpolation are described in Box 4-31 of EPA (2000), provided in Appendix A of the tabbed section titled, Appendices." The interpolation is illustrated using Table A-10 of EPA (2000). Double linear interpolation can be done in the same manner on Tables 3.2 and 3.3.

4. Calculate the (1-α)% UCL of the mean using the following equation:

$$UCL_{1-\alpha} = \exp\left[\bar{y} + \frac{s_y^2}{2} + \frac{s_y H_{1-\alpha}}{\sqrt{n-1}}\right] \qquad \text{Equation 3.2}$$



Microsoft Excel can be used to take natural logarithms and exponentiate, as well as calculate s_y, s_y^2, and $\bar{y}$. The Excel functions that should be used to obtain these values, respectively, are:

=LN(cell) =EXP(cell)

=STDEV(data range) =VAR(data range)

=AVERAGE(data range)



Interpretation: If the resulting *UCL* > criterion, conclude that the mean concentration is at or above the criterion. If *UCL* < criterion, conclude that the mean concentration is below the criterion.

Note that a more correct statement of the interpretation would be to conclude that the mean is at or above the Part 201 criterion if the UCL for the mean is greater than or equal to the criterion. However, because the data being evaluated are measured on a continuous scale, the probability of obtaining a UCL for the mean that is exactly equal to a given criterion is essentially zero. Therefore, the interpretation stated above will be relied upon for these comparisons.

Example 3.2 Sample Calculation of 95% UCL for the Mean of a Lognormally Distributed *RANDOM* Variable Using Land's Method

Fifteen soil samples were collected for analysis of arsenic concentrations. Using the methods described in Chapter 1, the data were concluded to be lognormally distributed. Figure 3.2 shows the data set, the log-transformed data set, and the calculations involved in determining a 95% UCL for the mean using Land's method. For this data set, the calculated values were $\bar{y}$ = 1.92, s_y^2 = 0.76, s_y = 0.87, and $H_{0.95}$ = 2.545. Using Equation 3.2, the 95% UCL for the mean arsenic concentration was 18.2 ppb. Note that this value is below three of the individual concentrations in the data set.

Figure 3.2 Spreadsheet Calculations of a 95% UCL Using Land's Method

	A	B	C	D	E	F	G	H
1	Observation	Arsenic	Ln (Arsenic)					
2	1	3.20	1.16		**n:**	15		
3	2	27.70	3.32			=COUNT(C2:C16)		
4	3	2.57	0.94					
5	4	9.98	2.30		**$\bar{y}$:**	1.92		
6	5	6.38	1.85			=AVERAGE(C2:C16)		
7	6	2.12	0.75					
8	7	2.80	1.03		**s_y^2:**	0.76		
9	8	12.11	2.49			=VAR(C2:C16)		
10	9	6.92	1.93					
11	10	5.32	1.67		**s_y:**	0.87		
12	11	23.19	3.14			=STDEV(C2:C16)		
13	12	7.02	1.95					
14	13	7.32	1.99		**$H_{0.95}$:**	2.545		
15	14	28.62	3.35			Interpolated value from Table 3.1		
16	15	2.59	0.95					
17			⌒		**Square bracket:**	2.90		
18			=LN(B2)			= F5 + F8 / 2 + F11 * F14 / SQRT(14)		
19			=LN(B3)					
20			⋮		**95% UCL:**	18.2		
21						=EXP(F17)		

3.1.3 Alternate Methods for Calculating UCLs for the Mean

As previously noted, the Student-t method and Land's method rely on assumptions of normality and lognormality, respectively. For data sets which are neither normal nor lognormal, alternative methods must be *PROPOSED* if departmental approval of a response activity is being sought.

3.1.3.1 Large Sample Methods

The Central Limit Theorem states that, for large sample sizes, the mean will tend to be normally distributed regardless of the distribution of the sampled population. A large sample method for computing a UCL for the mean is presented by Gilbert (1987, pg. 139). Large sample methods for calculating UCLs for the mean perform better as the number of samples increases. For smaller data sets with significant skewness, the method does not tend to perform well (Singh, et al. 1997). As an alternative, Chen (1995) describes a UCL that uses the Central Limit Theorem and incorporates an adjustment factor based on the skewness of the data set. This method is also described by Singh, et al. (1997). Because this method accounts for possible skewness in the data, it may provide more reasonable and accurate results than the standard large sample method presented by Gilbert for data sets that are right skewed.

However, for data sets that are highly skewed, Singh, et al. (1999) have found that these large sample methods do not provide adequate coverage for the mean (i.e., they may underestimate the mean concentration). Therefore, they should not be considered in this case unless the number of samples is sufficiently large. Gilbert (1987) suggests that, for highly skewed distributions, a sample size of 50 or more may be required. As always, it is important that the data set be identified as described in the appropriate Statistical Guidesheet (i.e., the data should be from samples within an appropriate *EXPOSURE UNIT* and should not include data representing *HOT SPOTS*).

Since these methods involve calculation of a mean and standard deviation, they should not be used for data sets with ≥ 50% nondetects.

Large sample methods for calculating UCLs for the mean concentration must be *PROPOSED* for review and approval if departmental approval of a response activity is being sought.

3.1.3.2 Alternative Methods for Small Data Sets and Data Sets With ≥ 50% Nondetects

For most *FACILITIES*, the number of samples in a given area (e.g., *EXPOSURE UNIT*) will generally be too small to consider the large sample methods described above. Statistical methods for calculating UCLs for the mean are generally not available for small data sets that are neither normally nor lognormally distributed. Consequently, additional samples may be collected according to a DEQ-approved sampling plan or alternate statistical methods may be *PROPOSED* to compare *FACILITY* data to Part 201 criteria.

For small data sets and for data sets with ≥ 50% nondetects, UCLs for a percentile may be considered in place of UCLs for a mean. Two methods for selecting a percentile are described below:

1) **Select a percentile that will provide an estimate of the mean of the distribution.** Since the goal is to estimate the mean concentration in a given area, a specific percentile (generally higher than the 50th percentile or median) may be selected on a case-by-case basis that will provide an estimate of the mean concentration. Parkin, et. al. (1990) describe a method for identifying a percentile to estimate the mean of a lognormal distribution. This method may be *PROPOSED* for right-skewed data sets that are approximately lognormal. Parkin's method may provide a useful alternative to Land's method for evaluating data sets that are concluded to be lognormal, but result in unreasonably high UCLs for the mean using the Land's method.

2) **Select a percentile that is higher than the percent of data below the detection limit.** For highly censored data sets, EPA (2000) suggests considering a percentile higher than the percent of data below the detection limit. For example, if 67% of the data are below the detection limit, EPA recommends consideration of a UCL for the 70th or 75th percentile to statistically compare data to a given criterion. This method, and a specified percentile for comparing data to criteria, may be *PROPOSED* if department approval of a response action is being sought.

Once a percentile has been selected, a nonparametric UCL for the percentile can be calculated to compare *FACILITY* data to Part 201 criteria. The method described by Gilbert (1987, pg. 141) may be *PROPOSED* for data sets with greater than 20 samples. Alternatively, for data sets with 20 or fewer samples, the procedure described by Conover (1980, pg. 112) may be *PROPOSED*.

Note: Past EPA guidance (1989c, 1992c) recommended use of a UCL for the median (i.e., the 50th percentile) when comparing data sets that are neither normal nor lognormal to fixed criteria. For populations with symmetric distributions, such as the normal distribution, the median and the mean are equivalent. However, the lognormal distribution is more commonly used to describe environmental data. This is because many environmental data sets have asymmetric distributions with a long right tail representing high concentration levels (i.e., right-skewed distributions).

For data sets which are lognormally distributed, the mean is always greater than the median. The median will underestimate the mean when the distribution of the data is right-skewed. Consequently, the selected percentile must generally be higher than the median, as described above. This recommendation is supported by more recent EPA guidance (2000), which recommends use of an upper percentile higher than the median for data sets with a CV > 0.5, particularly if the proportion of data below the detection limit is high (i.e., greater than 30 %).

3.2 NUMBER OF SAMPLES

When obtaining samples to characterize soils or waste materials, it is important to assure that the analytical results obtained will provide an accurate estimation of the nature of the entire area/volume under consideration. The location and number of discrete samples to be collected at a particular site depend on many factors: the degree of accuracy desired, the spatial and temporal variability of the media being sampled (e.g., soils, treated media, waste, etc.) to be sampled, and the costs involved. An important objective in any sampling program is to obtain the most accurate and representative data possible while minimizing the associated costs. One method to

accomplish this goal is to use statistically valid sampling strategies. The appropriate sample size can be estimated and the sampling locations can be chosen without bias.

Sample size, that is the number of samples to be collected, is a critical issue for determining compliance using UCLs for the mean. Larger numbers of samples result in lower UCLs for the mean. Although sample size analysis is not strictly necessary, it may be useful for demonstrating compliance.

The DEQ recommends a minimum of nine samples per *EXPOSURE UNIT*. However, when the sample mean concentration is close to the cleanup criterion, it may be beneficial to collect additional samples with the goal of lowering the UCL for the mean to demonstrate compliance. Following are three methods that can be considered during planning for sample collection.

3.2.1 Normal Distributions

When the underlying statistical distribution of the data set has been determined to be normal the appropriate number of samples required for waste characterization can be calculated by either of the following methods. Additional methods may also be *PROPOSED*.

3.2.1.1 Lambda Test

If the preliminary data indicate that more samples are needed to make a statistical comparison to Michigan's cleanup or waste classification criteria (e.g., the UCL for the mean is greater than the criterion, but the mean concentration is below), the Lambda (λ) relationship may be used to identify the number of samples necessary to demonstrate compliance. The total number of samples necessary to demonstrate compliance (assuming that the initial data were representative) can be estimated by use of the Lambda (λ) relationship and then consulting a table of values. A step by step approach to calculating the appropriate sample size follows:

1. Using data from the *n* initial samples, calculate λ

$$\lambda = \frac{C - \overline{X}}{s} \qquad \text{Equation 3.3}$$

Where:

C = the Part 201 criterion (or regulatory threshold for waste characterization),
$\overline{X}$ = the arithmetic mean of the data, and
s = the sample standard deviation.

The lower the resulting value for λ, the more samples are required to maintain a certain level of confidence. Also, as $\overline{X}$ approaches C, λ becomes smaller, and therefore a greater sample size is indicated for a certain level of confidence.

2. Refer to Table 3.4 to obtain the appropriate total sample size (n_{total}) from the table of values based on the resulting value for λ and a one-sided α at the desired significance level (α = 0.05 for comparison to Part 201 criteria). The resulting number of samples (n_{total}) reflects the total number of samples necessary to demonstrate compliance.

3. Determine the number of additional samples necessary (n_{total}-n). Collect the additional samples using the same sampling and analytical procedures as the first n samples. All field and laboratory procedures should be kept as consistent as possible to lower the amount of variability in the data.

4. Evaluate the spatial distribution of the combined data to determine if any new *HOT SPOTS* have been identified. If *HOT SPOTS* are present, these must be addressed separately.

5. Reevaluate the combined data (excluding *HOT SPOTS*) for statistical distribution as described in Chapter 1 and outliers (if apparent) as described in Chapter 2. Use all data values to calculate a new $\overline{X}$ and s.

6. If the new $\overline{X} \geq$ C, then a 95% UCL for the mean will clearly be above C and collection of additional samples is not likely to result in a UCL for the mean that is below C. Therefore, it can be concluded that the contaminant is present at an unacceptable concentration and the study would be complete.

7. If the new $\overline{X}$ < C, recalculate the 95% UCL for the mean as described in Section 3.1. If the new 95% UCL for the mean is below C, it can be concluded that the mean concentration is below the criterion (C) with 95% confidence. However, if the new 95% UCL for the mean is above C, either conclude that contaminant concentrations are unacceptable or start again at step 1.

3.2.1.2 SW-846 Method

An appropriate number of samples can also be calculated for a data set displaying the characteristics of a normal distribution by using the formula obtained from SW-846. This formula uses the t-statistic at the α level of significance with n-1 degrees of freedom.

$$n_{total} = \frac{t^2_{n-1,\alpha} s^2}{\Delta^2} \qquad \text{Equation 3.4}$$

Where:

Δ = C - $\overline{x}$
C = the Part 201 criterion or the regulatory threshold for waste characterization,
$\overline{x}$ = the arithmetic mean of the data set,
s^2 = the sample variance of the data set,
$t_{n-1, \alpha}$ = the appropriate t-statistic derived using degrees of freedom of n-1, and
n = the number of samples previously collected, and
n_{total} = the total number of samples to be collected.

For Part 201 comparisons table 3.1 is used with α = 0.05. When characterizing waste, the t-statistic is found by entering table 3.1 with α = 0.10. This method directly calculates the number of samples required (n_{total}) at the selected confidence level.

3.2.2 Lognormal Distributions

For a lognormal distribution, no simple established sample size formula, such as those presented above for normal distributions, is available which can be used to establish the number of samples necessary to achieve a specified error limit (EPA 1999). The use of the

Land's Method is recommended to define the confidence limit. Other methods may be *PROPOSED* to determine the appropriate sample size for lognormal distributions.

Sample Size Determination Using Land's Procedure for Lognormal Data

When data can be shown to be lognormally distributed, Land's procedure can be applied to calculate UCLs for the mean (Land, 1971 and 1975). For lognormally distributed populations, a UCL for the mean is (Gilbert 1987):

$$UCL = e^{\left(\bar{y}+\frac{s^2}{2}+\frac{sH}{\sqrt{n-1}}\right)} = \hat{X}e^{\left(\frac{sH}{\sqrt{n-1}}\right)}$$

To attain a UCL for the mean with 100*d*% relative error for the mean we require that:

$$\frac{UCL-\hat{X}}{\hat{X}} = e^{\left(\frac{sH}{\sqrt{n-1}}\right)} - 1 < d$$

Solving for *n*, a sample size formula to insure that Land's procedure results in confidence limits with 100xd% precision is given by

$$n_{total} \cong \frac{s^2 H_{1-\alpha}{}^2}{\left(\ln(1+d)\right)^2} + 1 \qquad \text{Equation 3.5}$$

Where:

s_y^2 = the variance of the log transformed data,
α = the significance level (α = 0.05 or 0.10), and
$H_{1-\alpha}$ = tabled value that can be obtained from Table 3.2 for α = 0.05 or Table 3.3 for α = 0.10,
n = the number of samples previously collected, and
n_{total} = the total number of samples to be collected.

For example, with s=0.2 and n ranging from 10 to 51, H ≈ 1.8. For d=0.1,

$$n = (0.2)^2(1.8)^2 / \log\left((1.1)\right)^2 + 1 = 15.3$$

Rounding up, the total sample n_{total} would be 16.

It should be noted that relative error term (d) must be specified in the original untransformed scale.

3.3 LOWER CONFIDENCE LIMITS FOR THE MEAN

Lower confidence limits (LCLs) for the mean provide a lower bound for the true mean concentration. When used to statistically compare *FACILITY* data to Part 201 criteria, the LCL for the mean corresponds to the following null and alternative hypotheses:

Hypothesis 2

H_o: The mean hazardous substance concentration in a given *EXPOSURE UNIT* is less than or equal to the Part 201 criterion

H_a: The mean hazardous substance concentration in a given *EXPOSURE UNIT* is greater than the Part 201 criterion

The baseline assumption in Hypothesis 2 is that the mean hazardous substance concentration is at or below its respective criterion unless the sample data provide sufficient evidence to conclude that the mean concentration is significantly above the criterion. Because the Part 201 cleanup program pertains to sites of environmental contamination, this set of assumptions generally does not apply. Furthermore, a review EPA statistical guidance documents indicates that EPA's recommendations regarding the use of LCLs for the mean are limited to the context of RCRA compliance monitoring (1989c, 1992c). As stated in the introduction to this chapter, UCLs for the mean are generally recommended by the EPA in the context of their cleanup programs (e.g., the Superfund program and RCRA Corrective Action).

Consequently, the baseline assumption under Hypothesis 2 will be justifiable only in limited circumstances under Michigan's Part 201 program. For example, an LCL for the mean may be justified for comparing hazardous substance concentrations to Part 201 criteria for the purpose of a *FACILITY* determination if there is no evidence to suggest that there has been a *RELEASE* anywhere on the property. Because of the limited utility of LCLs for the mean in demonstrating compliance with Part 201 criteria, this statistical method is not described in detail.

Table 3.1 Values of $t_{1-\alpha, n-1}$, α = 0.05, 0.10

Cumulative t Distribution

	α	0.10	0.05
	1	3.078	6.314
	2	1.886	2.920
	3	1.638	2.353
	4	1.533	2.132
	5	1.476	2.015
	6	1.440	1.943
	7	1.415	1.895
	8	1.397	1.860
	9	1.383	1.833
	10	1.372	1.812
	11	1.363	1.796
	12	1.356	1.782
	13	1.350	1.771
	14	1.345	1.761
	15	1.341	1.753
	16	1.337	1.746
	17	1.333	1.740
	18	1.330	1.734
df	19	1.328	1.729
(n-1)	20	1.325	1.725
	21	1.323	1.721
	22	1.321	1.717
	23	1.319	1.714
	24	1.318	1.711
	25	1.316	1.708
	26	1.315	1.706
	27	1.314	1.703
	28	1.313	1.701
	29	1.311	1.699
	30	1.310	1.697
	40	1.303	1.684
	60	1.296	1.671
	120	1.289	1.658
		1.282	1.645

Table 3.2 Land's Method Values for $H_{0.95}$. From Land (1975).

	n									
sy	3	5	7	10	12	15	21	31	51	101
0.10	2.750	2.035	1.886	1.802	1.775	1.749	1.722	1.701	1.684	1.670
0.20	3.295	2.198	1.992	1.881	1.843	1.809	1.771	1.742	1.718	1.697
0.30	4.109	2.402	2.125	1.977	1.927	1.882	1.833	1.793	1.761	1.733
0.40	5.220	2.651	2.282	2.089	2.026	1.968	1.905	1.856	1.813	1.777
0.50	6.495	2.947	2.465	2.220	2.141	2.068	1.989	1.928	1.876	1.830
0.60	7.807	3.287	2.673	2.368	2.271	2.181	2.085	2.010	1.946	1.891
0.70	9.120	3.662	2.904	2.532	2.414	2.306	2.191	2.102	2.025	1.960
0.80	10.43	4.062	3.155	2.710	2.570	2.443	2.307	2.202	2.112	2.035
0.90	11.74	4.478	3.420	2.902	2.738	2.589	2.432	2.310	2.206	2.117
1.00	13.05	4.905	3.698	3.103	2.915	2.744	2.564	2.423	2.306	2.205
1.25	16.33	6.001	4.426	3.639	3.389	3.163	2.923	2.737	2.580	2.447
1.50	19.60	7.120	5.184	4.207	3.896	3.612	3.311	3.077	2.881	2.713
1.75	22.87	8.250	5.960	4.795	4.422	4.081	3.719	3.437	3.200	2.997
2.00	26.14	9.387	6.747	5.396	4.962	4.564	4.141	3.812	3.533	3.295
2.50	32.69	11.67	8.339	6.621	6.067	5.557	5.013	4.588	4.228	3.920
3.00	39.23	13.97	9.945	7.864	7.191	6.570	5.907	5.388	4.947	4.569
3.50	45.77	16.27	11.56	9.118	8.326	7.596	6.815	6.201	5.681	5.233
4.00	52.31	18.58	13.18	10.38	9.469	8.630	7.731	7.024	6.424	5.908
4.50	58.85	20.88	14.80	11.64	10.62	9.669	8.652	7.854	7.174	6.590
5.00	65.39	23.19	16.43	12.91	11.77	10.71	9.579	8.688	7.929	7.277
6.00	78.47	27.81	19.68	15.45	14.08	12.81	11.44	10.36	9.449	8.661
7.00	91.55	32.43	22.94	18.00	16.39	14.90	13.31	12.05	10.98	10.05
8.00	104.60	37.06	26.20	20.55	18.71	17.01	15.18	13.74	12.51	11.45
9.00	117.70	41.68	29.46	23.10	21.03	19.11	17.05	15.43	14.05	12.85
10.00	130.800	46.31	32.73	25.66	23.35	21.22	18.93	17.13	15.59	14.26

Table 3.3 Land's Method Values for $H_{0.90.}$ From Land (1975).

	n									
sy	3	5	7	10	12	15	21	31	51	101
0.10	1.686	1.438	1.381	1.349	1.338	1.328	1.317	1.308	1.301	1.295
0.20	1.885	1.522	1.442	1.396	1.380	1.365	1.348	1.335	1.324	1.314
0.30	2.156	1.627	1.517	1.453	1.432	1.411	1.388	1.370	1.354	1.339
0.40	2.521	1.755	1.607	1.523	1.494	1.467	1.437	1.412	1.390	1.371
0.50	2.990	1.907	1.712	1.604	1.567	1.532	1.494	1.462	1.434	1.409
0.60	3.542	2.084	1.834	1.696	1.650	1.606	1.558	1.519	1.485	1.454
0.70	4.136	2.284	1.970	1.800	1.743	1.690	1.631	1.583	1.541	1.504
0.80	4.742	2.503	2.119	1.914	1.845	1.781	1.710	1.654	1.604	1.560
0.90	5.349	2.736	2.280	2.036	1.955	1.880	1.797	1.731	1.672	1.621
1.00	5.955	2.980	2.450	2.167	2.073	1.985	1.889	1.812	1.745	1.686
1.25	7.466	3.617	2.904	2.518	2.391	2.271	2.141	2.036	1.946	1.866
1.50	8.973	4.276	3.383	2.896	2.733	2.581	2.415	2.282	2.166	2.066
1.75	10.48	4.944	3.877	3.289	3.092	2.907	2.705	2.543	2.402	2.279
2.00	11.98	5.619	4.380	3.693	3.461	3.244	3.005	2.814	2.648	2.503
2.50	14.99	6.979	5.401	4.518	4.220	3.938	3.629	3.380	3.163	2.974
3.00	18.00	8.346	6.434	5.359	4.994	4.650	4.270	3.964	3.697	3.463
3.50	21.00	9.717	7.473	6.208	5.778	5.370	4.921	4.559	4.242	3.965
4.00	24.00	11.09	8.516	7.062	6.566	6.097	5.580	5.161	4.796	4.474
4.50	27.01	12.47	9.562	7.919	7.360	6.829	6.243	5.769	5.354	4.989
5.00	30.01	13.84	10.61	8.779	8.155	7.563	6.909	6.379	5.916	5.508
6.00	36.02	16.60	12.71	10.50	9.751	9.037	8.248	7.607	7.048	6.555
7.00	42.02	19.35	14.81	12.23	11.35	10.52	9.592	8.842	8.186	7.607
8.00	48.03	22.11	16.91	13.96	12.96	12.00	10.94	10.08	9.329	8.665
9.00	54.03	24.87	19.02	15.70	14.56	13.48	12.29	11.32	10.48	9.725
10.00	60.04	27.63	21.12	17.43	16.17	14.97	13.64	12.56	11.62	10.79

Table 3.4 Number of Observations for t-Test of the Mean

Level for *t* Test (α)

One-sided / Two-sided	α = 0.005 / = 0.01					α = 0.01 / = 0.02					α = 0.025 / = 0.05					α = 0.05 / = 0.1				
λ	β= 0.01	0.05	0.1	0.2	0.5	0.01	0.05	0.1	0.2	0.5	0.01	0.05	0.1	0.2	0.5	0.01	0.05	0.1	0.2	0.5
0.05																				
0.10																				
0.15																				122.0
0.20										139.0					99.0					70.0
0.25					110.0					90.0				128.0	64.0			139.0	101.0	45.0
0.30				134.0	78.0				115.0	63.0			119.0	90.0	45.0		122.0	97.0	71.0	32.0
0.35			125.0	99.0	58.0			109.0	85.0	47.0		109.0	88.0	67.0	34.0		90.0	72.0	52.0	24.0
0.40		115.0	97.0	77.0	45.0		101.0	85.0	66.0	37.0	117.0	84.0	68.0	51.0	26.0	101.0	70.0	55.0	40.0	19.0
0.45		92.0	77.0	62.0	37.0	110.0	81.0	68.0	53.0	30.0	93.0	67.0	54.0	41.0	21.0	80.0	55.0	44.0	33.0	15.0
0.50	100.0	75.0	63.0	51.0	30.0	90.0	66.0	55.0	43.0	25.0	76.0	54.0	44.0	34.0	18.0	65.0	45.0	36.0	27.0	13.0
0.55	83.0	63.0	53.0	42.0	26.0	75.0	55.0	46.0	36.0	21.0	63.0	45.0	37.0	28.0	15.0	54.0	38.0	30.0	22.0	11.0
0.60	71.0	53.0	45.0	36.0	22.0	63.0	47.0	39.0	31.0	18.0	53.0	38.0	32.0	24.0	13.0	46.0	32.0	26.0	19.0	9.0
0.65	61.0	46.0	39.0	31.0	20.0	55.0	41.0	34.0	27.0	16.0	46.0	33.0	27.0	21.0	12.0	39.0	28.0	22.0	17.0	8.0
0.70	53.0	40.0	34.0	28.0	17.0	47.0	35.0	30.0	24.0	14.0	40.0	29.0	24.0	19.0	10.0	34.0	24.0	19.0	15.0	8.0
0.75	47.0	36.0	30.0	25.0	16.0	42.0	31.0	27.0	21.0	13.0	35.0	26.0	21.0	16.0	9.0	30.0	21.0	17.0	13.0	7.0
0.80	41.0	32.0	27.0	22.0	14.0	37.0	28.0	24.0	19.0	12.0	31.0	22.0	19.0	15.0	9.0	27.0	19.0	15.0	12.0	6.0
0.85	37.0	29.0	24.0	20.0	13.0	33.0	25.0	21.0	17.0	11.0	28.0	21.0	17.0	13.0	8.0	24.0	17.0	14.0	11.0	6.0
0.90	34.0	26.0	22.0	18.0	12.0	29.0	23.0	19.0	16.0	10.0	25.0	19.0	16.0	12.0	7.0	21.0	15.0	13.0	10.0	5.0
0.95	31.0	24.0	20.0	17.0	11.0	27.0	21.0	18.0	14.0	9.0	23.0	17.0	14.0	11.0	7.0	19.0	14.0	11.0	9.0	5.0
1.00	28.0	22.0	19.0	16.0	10.0	25.0	19.0	16.0	13.0	9.0	21.0	16.0	13.0	10.0	6.0	18.0	13.0	11.0	8.0	5.0
1.1	24.0	19.0	16.0	14.0	9.0	21.0	16.0	14.0	12.0	8.0	18.0	13.0	11.0	9.0	6.0	15.0	11.0	9.0	7.0	
1.2	21.0	16.0	14.0	12.0	8.0	18.0	14.0	12.0	10.0	7.0	15.0	12.0	10.0	8.0	5.0	13.0	10.0	8.0	6.0	
1.3	18.0	15.0	13.0	11.0	8.0	16.0	13.0	11.0	9.0	6.0	14.0	10.0	9.0	7.0		11.0	8.0	7.0	6.0	
1.4	16.0	13.0	12.0	10.0	8.0	14.0	11.0	10.0	9.0	6.0	12.0	9.0	8.0	7.0		10.0	8.0	7.0	5.0	
1.5	15.0	12.0	11.0	9.0	7.0	13.0	10.0	9.0	8.0	6.0	11.0	8.0	7.0	6.0		9.0	7.0	6.0		
1.6	13.0	11.0	10.0	8.0	6.0	12.0	10.0	9.0	7.0	5.0	10.0	8.0	7.0	6.0		8.0	6.0	6.0		
1.7	12.0	10.0	9.0	8.0	6.0	11.0	9.0	8.0	7.0		9.0	7.0	6.0	5.0		8.0	6.0	5.0		
1.8	12.0	10.0	9.0	8.0	6.0	10.0	8.0	7.0	7.0		8.0	7.0	6.0			7.0	6.0			
1.9	11.0	9.0	8.0	7.0	6.0	10.0	8.0	7.0	6.0		8.0	6.0	6.0			7.0	5.0			
2.0	10.0	8.0	8.0	7.0	5.0	9.0	7.0	7.0	6.0		7.0	6.0	5.0			6.0				
2.1	10.0	8.0	7.0	7.0		8.0	7.0	6.0	6.0		7.0	6.0				6.0				
2.2	9.0	8.0	7.0	6.0		8.0	7.0	6.0	5.0		7.0	6.0				6.0				
2.3	9.0	7.0	7.0	6.0		8.0	6.0	6.0			6.0	5.0				5.0				
2.4	8.0	7.0	7.0	6.0		7.0	6.0	6.0			6.0									
2.5	8.0	7.0	6.0	6.0		7.0	6.0	6.0			6.0									
3.0	7.0	6.0	6.0	5.0		6.0	5.0	5.0			5.0									
3.5	6.0	5.0	5.0			5.0														
4.0	6.0																			
						99% confidence										95% confidence				

CHAPTER 4: COMPARISON OF *FACILITY* DATA TO *BACKGROUND*

As stated in Rule 701(c), the term *BACKGROUND* is defined as:

> *the concentration or level of a hazardous substance which exists in the environment at or regionally proximate to a site that is not attributable to any release at or regionally proximate to the site.*

According to Section 20a(11), when *BACKGROUND* concentrations of a hazardous substance are greater than the corresponding Part 201 risk-based criterion, *BACKGROUND* becomes the Part 201 criterion. Consequently, consideration of applicable Part 201 criteria is necessary before comparing *FACILITY* data to *BACKGROUND*. In general, *FACILITY* data will be compared to *BACKGROUND* concentrations only when *BACKGROUND* concentrations are greater than the applicable risk-based criterion.

When *BACKGROUND* concentrations are being considered, the objective becomes to determine whether the *FACILITY* concentrations are significantly higher than *BACKGROUND* concentrations for a hazardous substance. This determination may or may not involve a statistical comparison to *BACKGROUND*, depending on: 1) the type of *BACKGROUND* being considered, and 2) whether a statistical analysis of *FACILITY* data for comparison to *BACKGROUND* is appropriate.

The types of *BACKGROUND* that will generally be considered include: 1) *STATEWIDE DEFAULT BACKGROUND*, 2) *REGIONAL BACKGROUND*, and 3) *FACILITY-SPECIFIC BACKGROUND*. Additional information on each type of *BACKGROUND* is provided below.

In most cases, *FACILITY* data will be compared to *BACKGROUND* on a point-by-point basis. That is, concentrations of each hazardous substance in each *FACILITY* sample will be compared to directly to the *BACKGROUND* concentration and individual exceedances will be noted. When point-by-point comparisons are made, professional judgment is required to interpret the significance of exceedances that are very close to criteria or *BACKGROUND*, or that may be associated with insignificant quantities of a hazardous substance.

Statistical analysis of *FACILITY* data for comparison to *BACKGROUND* may be appropriate. Statistical Guidesheets for the applicable pathways/conditions should be consulted to determine the applicability of statistics for comparing *FACILITY* data to Part 201 criteria and key considerations for selection of the appropriate data set(s). Recommendations provided in the Statistical Guidesheets apply to all Part 201 criteria, including *BACKGROUND*. A statistical analysis of *FACILITY* data for comparison to *BACKGROUND* will most likely be appropriate for pathways/conditions categorized as **YES**, or for those categorized as **GNP** for which a statistical analysis is demonstrated to be appropriate.

Recommended methods for comparing *FACILITY* data to *BACKGROUND* are provided in the following sections:

Type of *BACKGROUND*	Statistical Analysis of *FACILITY* Data Appropriate?	Method for Comparing *FACILITY* Data to *BACKGROUND*
STATEWIDE DEFAULT BACKGROUND	No	Section 4.1.1
	Yes	Section 4.1.2
REGIONAL BACKGROUND	No	Section 4.2.1
	Yes	Section 4.2.2
FACILITY-SPECIFIC BACKGROUND	No	Section 4.3.1
	Yes	Section 4.3.2

Where the column "Statistical Analysis of *FACILITY* Data Appropriate?" is "No," a point-by-point comparison of *FACILITY* data to *BACKGROUND* concentrations is necessary.

If departmental approval of a response action is being sought, alternate statistical methods for comparing *FACILITY* data to *BACKGROUND* data may be *PROPOSED* on a case-by-case basis. Self-implemented response activities using statistics to support determinations must be documented in a manner that fully and clearly addresses the three questions outlined in the tabbed section titled, "Introduction."

4.1 *STATEWIDE DEFAULT BACKGROUND* CONCENTRATIONS

STATEWIDE DEFAULT BACKGROUND concentrations are provided in Operational Memorandum #15 for naturally occurring metals. (See Appendix B of the tabbed section titled, "Appendices.") For the purpose of statistical comparisons with *FACILITY* concentrations, the MDEQ considers these criteria to be fixed values, rather than statistically-derived numbers.

4.1.1 Point-by-Point Comparison of *FACILITY* Data to *STATEWIDE DEFAULT BACKGROUND* Concentrations

When the *BACKGROUND* concentration being used is a *STATEWIDE DEFAULT BACKGROUND* concentration, *FACILITY* concentrations will generally be compared to this value on a point-by-point basis. Therefore, in general, simply compare each individual *FACILITY* concentration to the *STATEWIDE DEFAULT BACKGROUND* value and note individual exceedances.

4.1.2 Statistical Comparison of *FACILITY* Data to *STATEWIDE DEFAULT BACKGROUND* Concentrations, When Appropriate

When comparing *FACILITY* data to a *STATEWIDE DEFAULT BACKGROUND* concentration and a statistical analysis of *FACILITY* data is documented to be appropriate, a 95% UCL for the mean of the *FACILITY* data set may be calculated for comparison to the *STATEWIDE DEFAULT BACKGROUND* concentration. This is the same approach taken for statistical comparison of *FACILITY* data to risk-based criteria since these criteria are also treated as fixed values.

Procedures for calculating a UCL for the mean are presented in Chapter 3. The first step is to determine the distribution of the *FACILITY* data set (Chapter 1) and whether outliers are present (Chapter 2). If the data are normally distributed, use Procedure 3.1 to calculate a 95% UCL for the mean ($UCL_{0.95}$) using the Student's t method and compare this value to the *STATEWIDE DEFAULT BACKGROUND* concentration. If the data are lognormally distributed, use Procedure 3.2 to calculate $UCL_{0.95}$ based on Land's method and compare this value to the *STATEWIDE DEFAULT BACKGROUND* concentration. Alternate methods may be *PROPOSED* on a case-by-case basis, if departmental approval of a response action is being sought.



Interpretation: If $UCL_{0.95}$ > *STATEWIDE DEFAULT BACKGROUND* value, conclude that the mean *FACILITY* concentration is above this value. If $UCL_{0.95}$ < *STATEWIDE DEFAULT BACKGROUND* value, conclude that the mean *FACILITY* concentration is below the *STATEWIDE DEFAULT BACKGROUND* concentration.

Note that a more correct statement of the interpretation would be to conclude that the mean is at or above the *STATEWIDE DEFAULT BACKGROUND* value if the 95% UCL for the mean is greater than or equal to the *BACKGROUND* value. However, because the data being evaluated are measured on a continuous scale, the probability of obtaining a 95% UCL for the mean that is exactly equal to the *STATEWIDE DEFAULT BACKGROUND* value is essentially zero. Therefore, the interpretation stated above will be relied upon for these comparisons.

4.2 *REGIONAL BACKGROUND* CONCENTRATIONS

REGIONAL BACKGROUND concentrations may be *PROPOSED* on a case-by-case basis for comparison to *FACILITY* data. *REGIONAL BACKGROUND* data are typically considered in one of two manners:

1) **Development of a *REGIONAL BACKGROUND* concentration:** Data provided in sources such as the 1991 Michigan *BACKGROUND* Soil Survey (MBSS) can be *PROPOSED* to develop a *REGIONAL BACKGROUND* concentration. The MBSS should not generally be used as the only source of information for this purpose because the data in this survey do not equally represent all areas in Michigan (i.e., large numbers of *BACKGROUND* samples were collected at some locations, but small numbers or no samples in others). This yields a disproportionate weight to the locations with large numbers of samples. Other potential sources of data include approved *FACILITY-SPECIFIC BACKGROUND* data for *FACILITIES* in the nearby region, data published by the United States Geological Survey or other approved sources. Once a regional data set has been compiled, the statistical method for calculating a *REGIONAL BACKGROUND* concentration must also be *PROPOSED* on a case-by-case basis if departmental approval of a response action is being sought.

2) **Use of Professional Judgment:** In some cases, professional judgment based on general knowledge of *BACKGROUND* conditions in the region is used rather than the more rigorous approach described above. For example, if *FACILITY* concentrations are generally within the range of *BACKGROUND* concentrations that have been approved at other *FACILITIES* or are known to be present nearby within the region, it could be concluded that the *FACILITY* concentrations comply with *REGIONAL BACKGROUND* concentrations.

4.2.1 Point-by-Point Comparison of *FACILITY* Data to *REGIONAL BACKGROUND* Data

The method for establishing a *REGIONAL BACKGROUND* concentration and the *REGIONAL BACKGROUND* data used for this purpose must generally be *PROPOSED* on a case-by-case basis if departmental approval of a response action is being sought.

When a *BACKGROUND* concentration has been established as a *REGIONAL BACKGROUND* concentration, *FACILITY* concentrations will generally be compared to the *REGIONAL BACKGROUND* concentration on a point-by-point basis. Therefore, in general, simply compare each *FACILITY* concentration to the *REGIONAL BACKGROUND* concentration and note individual exceedances.

4.2.2 Statistical Comparison of *FACILITY* Data to *REGIONAL BACKGROUND* Data, When Appropriate

When the *BACKGROUND* concentration has been established as a *REGIONAL BACKGROUND* concentration and a statistical analysis of *FACILITY* data is appropriate, a statistical analysis of *FACILITY* data may be conducted for comparison to *REGIONAL BACKGROUND.* The method for comparing *FACILITY* data to *REGIONAL BACKGROUND* data must be *PROPOSED* on a case-by-case basis if departmental approval of a response action is being sought.

4.3 *FACILITY-SPECIFIC BACKGROUND* CONCENTRATIONS

Comparison of *FACILITY* data to *FACILITY-SPECIFIC BACKGROUND* concentrations has historically been completed using the mean plus three standard deviations calculated using *FACILITY-SPECIFIC BACKGROUND* data. This method of deriving *BACKGROUND* concentrations is still allowable in certain circumstances, as described in Section 4.3.1. However, it should be noted that this upper limit statistically represents the expected variability of sample results in an uncontaminated area, not a mean concentration; consequently, **only individual *FACILITY* concentrations may be compared to the mean plus three standard deviations**. **It is not appropriate to compare a mean concentration or a UCL for the mean concentration to an upper limit for *BACKGROUND* calculated as the mean plus three standard deviations.**

If a statistical analysis of *FACILITY* data is demonstrated to be appropriate for comparison to *BACKGROUND*, an alternative to the mean plus three standard deviation approach may be taken to compare *FACILITY* concentrations to *FACILITY-SPECIFIC BACKGROUND* concentrations, as described in Section 4.3.2. The recommended methods described in this section may be used to statistically compare the two populations represented by *FACILITY* concentrations and *FACILITY-SPECIFIC BACKGROUND* concentrations.

4.3.1 Point-by-Point Comparison of *FACILITY* Data to *FACILITY-SPECIFIC BACKGROUND* Data

When a *BACKGROUND* concentration has been established as a *FACILITY-SPECIFIC BACKGROUND* concentration, *FACILITY* concentrations will generally be compared to the *FACILITY-SPECIFIC BACKGROUND* concentration on a point-by-point basis. Therefore, in general, simply compare each individual *FACILITY* concentration to the *FACILITY-SPECIFIC BACKGROUND* concentration and note individual exceedances.

4.3.1.1 Normal or Lognormal Distributions

A *FACILITY-SPECIFIC BACKGROUND* concentration may be established as described in Procedure 4.1. This procedure is recommended for *FACILITY-SPECIFIC BACKGROUND* data sets that are either normally or lognormally distributed. If departmental approval of a response action is being sought, *PROPOSALS* must be made to calculate *FACILITY-SPECIFIC BACKGROUND* concentrations using alternative approaches.

Before calculating the *FACILITY-SPECIFIC BACKGROUND* concentration, it is still necessary to evaluate the data set for underlying statistical distribution (i.e., normal, lognormal, or neither) and the presence of outliers using the methods described in Chapters 1 and 2, respectively. If potential outliers are identified based on a review of the tabulated data and/or graphs of the data, formal outlier testing should be completed as described in Chapter 2, taking into account the underlying statistical distribution of the data.

Figure 4.1 Data and Calculations for Determining the *FACILITY-SPECIFIC BACKGROUND* Concentration and Evaluating for Exceedances

	A	B	C	D	E	F	G
1							
2		Background	Facility				
3	Observation	Conc.	Conc.	Exceeds?			
4	1	24.4	25.0	No		BG average:	25.1
5	2	22.4	29.7	No		=AVERAGE(B4:B13)	
6	3	25.5	31.1	No			
7	4	27.6	28.4	No		BG stdev:	2.6
8	5	27.4	23.8	No		=STDEV(B4:B13)	
9	6	28.5	34.2	Yes			
10	7	20.6	24.3	No	Facility-specific BG conc:		32.8
11	8	24.5	26.4	No		= G4 + 3 * G7	
12	9	27.2	42.6	Yes			
13	10	22.8	30.5	No			
14	11		31.0	No			
15	12		30.9	No			

Example 4.1 Sample Calculation of a *FACILITY-SPECIFIC BACKGROUND* Concentration

Suppose that 10 *FACILITY-SPECIFIC BACKGROUND* observations and 12 *FACILITY* observations of lead concentrations were collected. The data are provided in the spreadsheet below (Figure 4.1). No apparent outliers were present in the *FACILITY-SPECIFIC BACKGROUND* data. Using the methods outlined in Procedure 4.1, the average *BACKGROUND* concentration was estimated as 25.1 ppm and the standard deviation was 2.6 ppm. The resulting *FACILITY-SPECIFIC BACKGROUND* concentration was 32.8 ppm. Two exceedances were noted (34.2 and 42.6 ppm) as shown below.

Procedure 4.1 Determining a *FACILITY-SPECIFIC BACKGROUND* Concentration

1. For less than 50% nondetects, calculate the sample mean ($\bar{x}$) and sample standard deviation (*s*) using the following equation and substituting 1/2 of the detection limit for nondetects. (Equations 1.1 and 1.2 are reproduced below for convenience.)

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}}$$

2. For less than 50% nondetects, use the above values for $\bar{x}$ and s to calculate the *FACILITY-SPECIFIC BACKGROUND* concentration as:

$$\bar{x} + 3s$$

   For 50% nondetects or more, calculate the *FACILITY-SPECIFIC BACKGROUND* concentration using a nonparametric upper tolerance limit (EPA 1992c). This value should be determined as the maximum detected concentration in the *FACILITY-SPECIFIC BACKGROUND* data set.

3. Compare the *FACILITY* concentrations to the *FACILITY-SPECIFIC BACKGROUND* concentration on a point-by-point basis* and note exceedances.



In most cases, it should not be necessary to calculate the above equations by hand considering the availability of basic statistical computations in statistical software packages and most spreadsheet packages. Most statistical software packages provide the sample mean ($\bar{x}$) and the sample standard deviation (s). Alternatively, Microsoft Excel can be used to obtain $\bar{x}$ and *s*. The Excel functions that should be used to obtain these values, respectively, are:

=AVERAGE(data range)
=STDEV(data range)

* When point-by-point comparisons are made, professional judgment is required to interpret the significance of exceedances that are very close to criteria or *BACKGROUND*, or that may be associated with insignificant quantities of a hazardous substance.

4.3.1.2 Alternate Methods for Calculating *FACILITY-SPECIFIC BACKGROUND* Concentrations

Alternate methods are available for calculating *FACILITY-SPECIFIC BACKGROUND* concentrations. These methods include upper tolerance limits and upper prediction limits, among others. Upper tolerance limits and upper prediction limits are described in many documents and texts, including those by EPA (1992c), Gibbons (1994), Gibbons and Coleman (2001), Helsel and Hirsch (1992), and Millard and Neerchal (2001).

Use of alternate methods must be *PROPOSED* if departmental approval of a response action is being sought.

4.3.2 Statistical Comparison of *FACILITY* Data to *FACILITY-SPECIFIC BACKGROUND* Data, When Appropriate

If a statistical analysis of the *FACILITY* data is appropriate, statistical testing may be conducted to evaluate whether the population represented *FACILITY* data is signficantly greater than the population represented by *FACILITY-SPECIFIC BACKGROUND* data. A statistical comparison of two populations is referred to as a "two-sample test." Recommended two-sample tests (EPA 2000) include: 1) Student's t-test, 2) Satterthwaite's t-test, or 3) Wilcoxon Rank Sum test followed by the Quantile test. Selection of the appropriate test depends upon an evaluation of the underlying assumptions of these tests, as described below.

Two-sample testing is an alternative to the approach described in Section 4.3.1 because the focus is no longer on individual exceedances of a *BACKGROUND* value. Rather, two-sample tests typically compare some parameter of the population distributions, such as the mean. The Student t-test and Satterthwaite's t-test both provide methods for identifying differences in mean concentrations. The Wilcoxon Rank Sum test can be conducted to test for differences in the median concentration. The EPA (2000) recommends that the Wilcoxon Rank Sum test be conducted and interpreted together with the Quantile test. The Quantile test allows for detection of instances where only parts of the data set are different, rather than a complete shift in the data set. The EPA (2000) recommends this "tandem testing" approach since the combined tests are most powerful for detecting true differences between two population distributions.

Because EPA's *Guidance for Data Quality Assessment* (EPA, 2000) contains detailed explanations of the procedures for conducting the two-sample tests recommended in this section, this EPA document has been referenced as a source for descriptions of these tests. Excerpts from EPA (2000) are provided in Appendix A of the tabbed section titled, "Appendices."

Regardless of whether a statistical analysis is appropriate to compare *FACILITY* data to risk-based criteria, it is necessary to compute a *FACILITY-SPECIFIC BACKGROUND* concentration as described in Procedure 4.1 to determine if *BACKGROUND* is higher than the corresponding risk-based criteria. If the resulting *BACKGROUND* mean plus three standard deviations is greater than the risk-based criterion for a given hazardous substance, then this value becomes the Part 201 criterion for that hazardous substance. However, if the resulting *BACKGROUND* mean plus three standard deviations is not greater than the risk-based criterion, *BACKGROUND* does not become the Part 201 criterion and no further comparisons to *FACILITY-SPECIFIC BACKGROUND* are relevant.

4.3.2.1 Parametric Methods for Comparing *FACILITY-SPECIFIC BACKGROUND* and *FACILITY* Data Sets

First, determine the percent of nondetects in the combined data set. That is, combine the *FACILITY-SPECIFIC BACKGROUND* and *FACILITY* data sets determine the percent nondetect. If the percent nondetect in the combined data sets is ≥ 15%, proceed to Section 4.3.2.2.

If the combined data set is < 15% nondetect, determine the distribution of the *FACILITY-SPECIFIC BACKGROUND* and *FACILITY* data sets separately (Chapter 1). That is, complete the methods described in Chapter 1 for both data sets individually.

Next, evaluate each data set for potential outliers. If outliers are suspected, formal testing should be completed as described in Chapter 2. If sufficient data remain to allow for a valid statistical analysis, proceed as follows:

If both data sets are normally distributed, or both data sets are lognormally distributed, conduct Levene's test for equality of variances between the two data sets. The procedure for conducting Levene's test can be found in Box 4-26 on page 4-37 and an example can be found in Box 4-27 on page 4-38 of EPA (2000). These pages are provided in Appendix A of the tabbed section titled, "Appendices."

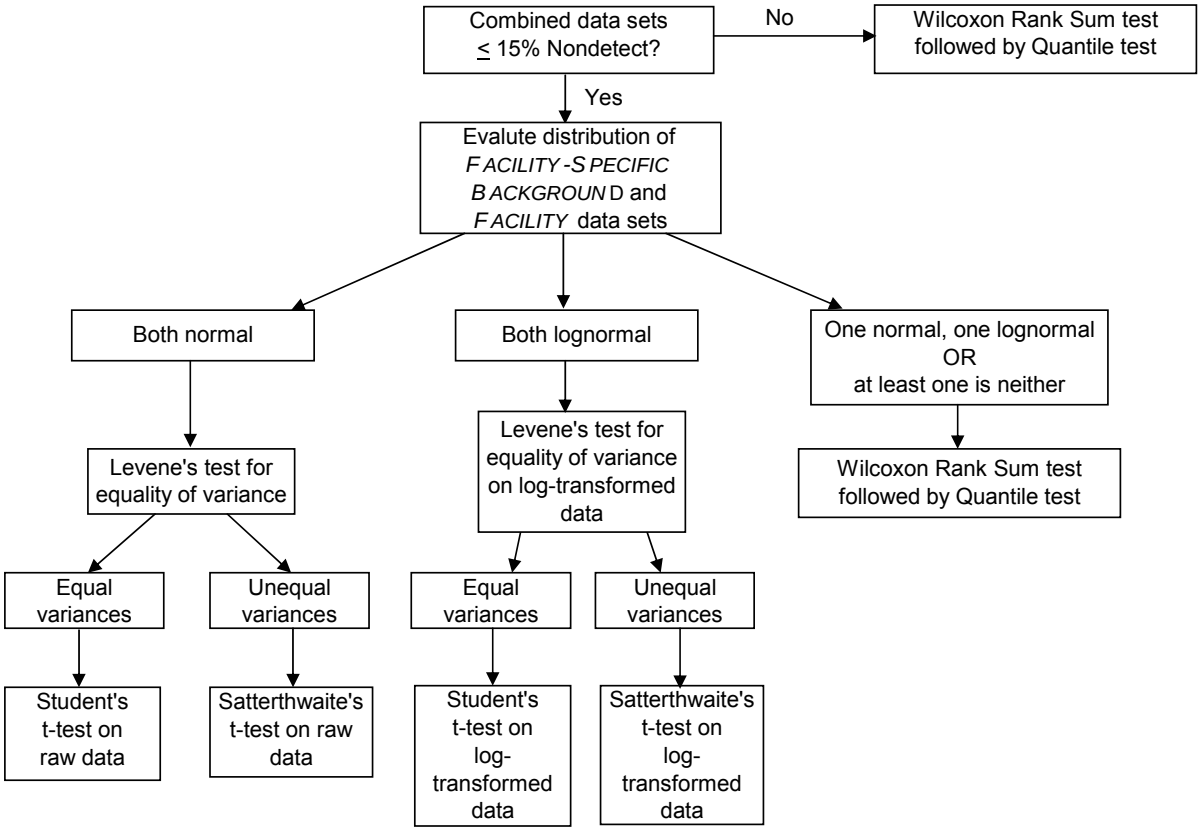
- If both data sets are normal and Levene's test indicates that variances of the data sets are equal, conduct the Student's t-test using the raw, untransformed data. Equality of variance is necessary since the Student's t-test assumes that both populations have equal variance. If both data sets are lognormal and the variances of the data sets are concluded to be equal, conduct the Student's t-test using log-transformed data. The procedure for conducting the Student's t-test and an example can be found in Box 3-14 on page 3-24 and Box 3-15 on page 3-25 of EPA (2000), respectively. These pages are provided in Appendix A of the tabbed section titled, Appendices."

- If both data sets are found to be normal and Levene's tests indicates that data sets do not have equal variances, conduct Satterthwaite's t-test using the raw, untransformed data. Satterthwaite's t-test provides an alternative to the Student's t-test when the populations being compared have unequal variances. If both data sets are lognormal and the variances of the data sets are not equal, conduct Satterthwaite's t-test using log-transformed data. Details for conducting Satterthwaite's t-test and an example can be found in Box 3-16 on page 3-26 and Box 3-17 on page 3-27 in EPA (2000), respectively. These pages are provided in Appendix A of the tabbed section titled, "Appendices." As noted by Millard and Neerchal (2001), it is important to decide whether it makes sense to focus on a difference in mean concentrations if you already know there is a difference in the variances. If this is the case, consider evaluating the data using the methods described in Section 4.3.2.2.

- If one data set is found to be normal and the other is found to be lognormal or if either data set is found to be neither normal nor lognormal, compare the data sets using the Wilcoxon Rank Sum Test followed by the Quantile Test, as described in Section 4.3.2.2.

See Figure 4.2 for a flowchart describing selection of the appropriate two-sample test.

Figure 4.2 Selection of Appropriate Two-Sample Test for Comparison of *FACILITY* Data to *FACILITY-SPECIFIC BACKGROUND* Data, When Appropriate



4.3.2.2 Nonparametric Methods for Comparing *FACILITY-SPECIFIC BACKGROUND* and *FACILITY* Data Sets

Nonparametric (i.e., distribution-free) methods for comparing *FACILITY-SPECIFIC BACKGROUND* data to *FACILITY* data are recommended when:

- One data set is found to be normal and the other is found to be lognormal, or
- Either data set is found to be neither normal nor lognormal, or
- The percent of nondetects in the combined data set is ≥ 15% (EPA 1992c).

The recommended nonparametric method involves comparing the data sets using the Wilcoxon Rank Sum Test followed by the Quantile Test. Directions for conducting a Wilcoxon Rank Sum Test can be found in Box 3-20 on page 3-32 and an example can be found in Box 3-21 on page 3-33 of EPA (2000). A large sample approximation to the Wilcoxon Rank Sum Test is provided in Box 3-22 on page 3-34 of EPA (2000) for comparing data sets each containing 20 or more samples. The Quantile Test is discussed on page 3-35 of EPA (2000). Directions for conducting a modified Quantile test can be found in Box 3-23 on page 3-36 and an example can be found in Box 3-24 on page 3-37 of EPA (2000). Each of these pages is provided in Appendix A of the tabbed section titled, "Appendices."

Although the Wilcoxon Rank Sum test can be done using a spreadsheet, the Quantile test is rather difficult to compute. S-PLUS contains functions that can perform both of these tests.

4.4 *BACKGROUND* CONCENTRATIONS FOR GROUNDWATER

Some issues particular to calculating *BACKGROUND* groundwater concentrations deserve special consideration. Careful consideration should be given to the selection of an appropriate *BACKGROUND* groundwater data set. First, *BACKGROUND* groundwater data should adequately represent *BACKGROUND* conditions. A sufficient number of groundwater samples should be collected over a time frame that will reflect seasonal variation (e.g., quarterly samples for two years). When *BACKGROUND* groundwater concentrations are established using upgradient wells, the number of wells should be sufficient to represent natural spatial variability.

BACKGROUND groundwater data should be closely evaluated for natural spatial variability and between-well variability before pooling data from upgradient wells for calculation of *BACKGROUND* concentrations. A *BACKGROUND* data set should represent a single population that can be described by a single statistical distribution (e.g., a normal distribution with a mean of 3.6 and a standard deviation of 0.78). *BACKGROUND* groundwater data should, therefore, be evaluated to determine if more than one population or distribution is present (e.g., due to the presence of multiple aquifers or significant spatial variability across an aquifer). This evaluation can be completed through a general review of the data or by using graphical techniques such as probability plots, side-by-side box plots, and/or stiff diagrams. It is generally not appropriate to combine data from different aquifers or from significantly differing areas, if present within an aquifer. Inappropriately combining data across wells can result in inflated *BACKGROUND* concentrations due to the large overall variability.

BACKGROUND groundwater data should be independent. In general, this means that: 1) the data should be *RANDOMLY* obtained, and 2) there should be no trends in the data. For groundwater monitoring purposes, samples are typically collected at fixed time intervals from wells which have been located based on professional judgment. Consequently, groundwater samples are not generally *RANDOM* with respect to space or time. However, it is important that

time intervals between samples be spaced far enough apart, considering groundwater flow rates, that groundwater samples are independent (i.e., the same groundwater is not sampled each time). Furthermore, data used to establish *BACKGROUND* groundwater concentrations should be non-trending. Use of trending data to establish *BACKGROUND* groundwater concentrations will result in inflated *BACKGROUND* concentrations.

Once *BACKGROUND* groundwater concentrations have been established, it may be necessary to reevaluate and/or update the *BACKGROUND* concentrations on a periodic basis. Revisions to *BACKGROUND* groundwater concentrations must be *PROPOSED* for DEQ approval.

The statistical methods described in Chapter 1 (evaluating statistical distributions) and Chapter 2 (evaluating for outliers) of this tabbed section are also appropriate for evaluating *BACKGROUND* groundwater data. In addition, the methods presented in Section 4.3.1 of Chapter 4 for calculating upper limits based on *FACILITY-SPECIFIC BACKGROUND* data are generally appropriate and can be used for calculating *BACKGROUND* groundwater concentrations.

Additional information and detail will be forthcoming in future statistics training materials. Any questions or reviews regarding statistic analyses of groundwater data for Part 201 applications should be submitted to the Department Statistician.

CHAPTER 5: CENSORED DATA

Contaminant concentrations often lie below the detection limits of the equipment used to estimate the concentrations of the contaminants. For these samples, instead of reporting an actual concentration, the detection limit of the equipment is typically reported (e.g., less than 7 ppb). The true concentration at the sampled location is likely below this detection limit, but how far below the limit is left to speculation. These types of data are termed **censored**.

Censored data can be rather difficult to deal with statistically. As one person put it, "censored data is like holding on to a tail and being unsure whether the other end is connected to an elephant or a mouse." This analogy gets at the heart of the difficulty that censored data presents. As you might imagine, if we have a five quantified observations above and five censored observations below some detection limit, then determining a "good" estimate of the mean, variance, or even the type of distribution (e.g., normal or lognormal) can be difficult.

Censored data can either be singly or multiply censored. Singly censored means that the data set contains only one censoring level or detection limit (e.g., < 7 ppb). A multiply-censored data set contains multiple censoring levels or detection limits (e.g., data may be reported at < 7 ppb, < 5 ppb, and < 3 ppb). A singly-censored data set is much easier to deal with than a multiply censored data set.

Recommendation

A simple approach for dealing with censored data has been to simply replace the censored observations with half of their respective detection limits. This method was found to perform adequately when calculating upper confidence limits (UCLs) for the mean concentration based on simulation studies conducted during the preparation of the draft document, Statistical Analysis of Ground-Water Monitoring Data at RCRA *FACILITIES* – Unified Guidance.

After substituting 1/2 of the detection limit for concentrations below the limit of detection, proceed with the analysis as usual by evaluating the distribution of the resulting data set (Chapter 1), examining for outliers (Chapter 2), and calculating UCLs for the mean when appropriate (Chapter 3).

This approach is recommended only for data sets with less than 50% nondetects.

When calculating a *FACILITY-SPECIFIC BACKGROUND* concentration as the mean plus three standard deviations for comparison to *FACILITY* data (Chapter 4), 1/2 of the detection limit may also be substituted for *FACILITY-SPECIFIC BACKGROUND* concentrations below the detection limit up to 50% nondetect. For greater than 50% nondetects, nonparametric upper tolerance limits may be used to obtain a *FACILITY-SPECIFIC BACKGROUND* concentration. As described by EPA (1992c), the upper limit may be established as the maximum concentration in the *FACILITY-SPECIFIC BACKGROUND* data set.

When conducting two-sample tests, such as those used to compare two populations (i.e., *FACILITY* concentrations and *FACILITY-SPECIFIC BACKGROUND* concentrations), nonparametric procedures should be used in place of parametric procedures when the percent of concentrations below the detection limit is greater than 15% in either data set, as recommended by EPA (1992c). The nonparametric procedure recommended in Chapter 4 is the Wilcoxon Rank Sum Test followed by the Quantile Test.

Alternate Methods

Several alternate methods are available for estimating the mean and standard deviation of censored data sets. Two of these are Cohen's method and Aitchison's method (EPA, 1992c). Cohen's method is based on the assumption that the censored observations belong to the same continuous distribution as the detected observations, except that they are censored at the detection limit (Cohen, 1991). Aitchison's method is based on the assumption that censored observations actually represent zero concentrations and detected values arise from some other distribution (Aitchison, 1955). These methods may be *PROPOSED*; however, it is necessary to evaluate the underlying assumptions and justify the choice between the two methods.

Censored and detects-only probability plots may be used to determine if Cohen's method or Aitchison's method is more appropriate for a given data set. These plots are described in detail in EPA (1992c). If the censoring appears to be of the Aitchison type, the data set should be evaluated further to determine whether two populations were being sampled (i.e., one represented by zero values and another represented by detected values) before proceeding with Aitchinson's method for handling nondetects. This could be achieved by examining the spatial distribution of the samples and their associated values.

Additional statistical methods for dealing with censored data are available and may be *PROPOSED* on a case-by-case basis, where departmental approval of a response action is being sought. These methods are generally too complex to implement using spreadsheet software. EnvironmentalStats for S-PLUS has several built-in functions that can be used to estimate a mean, variance, or even a UCL for the mean based on a singly or multiply censored data set.

Unfortunately, there are only a few studies that examine the performance of the various methods for calculating UCLs for the mean with censored data. Schmee et al. (1985) provides exact confidence limits, using maximum likelihood, for the parameters of a normal or lognormal distribution for various sample sizes and levels of single censoring. Millard and Neerchal (2001) provide the results of simulations examining confidence interval coverage probabilities using various sample sizes, levels of censoring, types of distributions, and methods of estimation using the functions within EnvironmentalStats for S-PLUS. As mentioned earlier, this software package contains several methods for calculating a UCL for the mean with censored data. Consult with a statistician to choose among the available methods and determine which is most appropriate for the situation at hand.

SOLID AND HAZARDOUS WASTE CHARACTERIZATION

SOLID AND HAZARDOUS WASTE CHARACTERIZATION

1.0 WASTE CHARACTERIZATION

For the purpose of waste characterization, it is assumed that there is no knowledge of the origin, process of generation or history of the material to be characterized and that the characteristics and waste class need to be determined through sampling and analysis. If sufficient knowledge of the material exists, sampling and/or statistical analysis may be reduced or eliminated.

The considerations presented here apply to any waste characterization required under the NREPA (Part 111, for Hazardous Waste Management or Part 115, Solid Waste Management). The appropriate DEQ staff must be consulted for an inertness designation for solid wastes (Part 115) and de-list petitions for listed hazardous wastes (Part 111). Other methods of determining waste classifications are available, but must be reviewed and approved by the appropriate DEQ staff.

Before statistical methods can be considered for comparing data to the appropriate criteria, the nature (waste process origin) and extent (the horizontal and vertical extent of the material) of the waste media in question, must first be defined. This information will aid in designing the sampling strategy to adequately characterize the material (i.e., identify if there is a single, homogeneous population that can be described by a single statistical distribution or whether there are *HOT SPOTS* present). Refer to the tabbed section titled, "Sampling Strategies" for more details on sampling options.

Each unique waste type must be characterized independently due to the heterogeneous nature of the waste material and the potential for stratification.

In general, compositing of samples is not recommended under any circumstances, but for volatile organic sampling it is never acceptable. Use of composite samples should be discussed with the appropriate DEQ staff.

2.0 IDENTIFICATION OF SAMPLING STRATEGIES

When obtaining samples to characterize a material, it is important to insure that the analytical results obtained will provide an accurate estimation of the nature of the entire area/volume under consideration. The location and number of samples to be taken of a particular material depend on many factors: the degree of accuracy desired, the spatial and temporal variability of the material to be sampled, and the costs involved. An important objective in any sampling program is to obtain the most accurate data possible while minimizing the associated costs. One method to accomplish this goal is to use statistically valid sampling strategies. The appropriate sample number can be estimated and the sampling intervals (which may be based on volume, location depth or time) can be chosen without bias.

A combination of sampling strategies may be necessary when characterizing wastes. The nature and extent of the material (boundaries) must be adequately defined. Biased sampling should generally be used to determine whether the material is **homogeneous** (i.e. origin with little variability), **heterogeneous** (i.e. origin with a great deal of variability) and/or **stratified**. Each unique waste type must be characterized independently. Biased sampling results may be sufficient to characterize a waste material depending on: 1) whether the biased sampling results adequately represent the waste materials, and 2) whether any individual sample result

exceeds the regulatory threshold of interest. If one or more samples exceed the regulatory threshold, a more extensive sampling may be pursued to apply a statistical analysis to compare the new characterization data to the regulatory threshold.

If a statistical analysis is to be used to compare characterization data to a regulatory threshold, it will be necessary to reevaluate data needs. Additional data will often be necessary for the purpose of calculating an upper confidence limit (UCL) for the mean concentration. These data should be obtained through statistical or *RANDOM* sampling.

If several materials on a site are under investigation, it is advisable to evaluate them separately. This is especially true if information does not exist to indicate that the materials contain similar constituents or that they were placed at the same time period.

2.1 Biased Sampling

"Biased" sampling strategies generally involve use of judgment to collect samples from areas most likely to contain contamination. Often, biased sampling is utilized for smaller areas (e.g., less than a 1/4 acre) and/or smaller volumes of materials. However, biased sampling also plays a role when characterizing large volumes of materials. In this case, biased sampling may be used to initially determine the homogeneity or heterogeneity of waste materials.

Use of biased sampling is premised on enough detailed information on which to base selection of sample locations. The sample locations are purposefully chosen based on the goal of identifying localized areas or volumes in which contaminant concentrations are elevated (i.e., *HOT SPOTS*). With sufficient knowledge of existing conditions, historic activities, or field indicators (e.g., visual, olfactory, or field screening instrumentation), these areas can be focused on reliably.

Any biased sampling plan requires use of professional judgment. A thorough justification must be documented for each sample location explaining the rationale used to select the location. Without this important detail, biased sampling alone will not be adequate.

Analytical results from biased sampling must generally be compared to regulatory thresholds on a point-by-point basis. A statistical analysis of data generated from biased sampling is generally not appropriate. This is due to the underlying assumptions of most statistical methods used to compare characterization data to regulatory thresholds. One underlying assumption is that the data being evaluated were obtained through *RANDOM* sampling of a single, homogeneous population that can be described by a single statistical distribution (e.g., a normal distribution with a mean of 3.6 and a standard deviation of 0.78). Biased sampling can be used to help identify if this is the case or if differing populations (e.g., *HOT SPOTS*) are present.

If statistical sampling is completed in addition to biased sampling, it may be appropriate to combine analytical results from the statistical sampling with some or even all of the biased sampling results in a statistical analysis. However, there are several key considerations which must first be addressed, as described in Section 3.2.

Biased sampling strategies require collection of discrete soil samples. Compositing of samples is not accepted without prior DEQ approval.

2.1.1 Sampling Process Streams

Although sampling is generally thought to occur on a pile of material or over an area of treated soil, other schemes are possible. Process wastes are commonly sampled at the point of generation. This is the preferred method, since it is most representative of the material under study. The lack of exposure to elements that might cause chemical degradation and/or leaching will result in material most indicative of actual conditions. A sampling point along the material conveyor that can be fairly easily and safely reached should be chosen. It should be in an area where the entire belt can be accessed for sampling. Sampling intervals can be assigned by specific process intervals, by generated volume (see Table 2.1 below) or by a timed interval that would represent key process time/volume.

When biased sampling is conducted for the purpose of waste characterization, it should account for process variability. Ideally, the entire active time of the waste process stream would be represented in the sampling scheme, but selected times and volumes should be identified for specific sampling (i.e., to provide a basis for biased sampling).

2.1.2 Sampling Ex Situ/Waste Piles

The number of samples to be collected from a waste pile should be based on the volume of the waste pile. The following table provides recommended numbers of samples for waste characterization using biased sampling.

Table 2.1 Number of Biased Samples for Waste Piles

Volume (cubic yards)	0-25	26-100	101-500	501-1,000	1,001-2,000	> 2,000
Number of samples (depending on basis of bias)	3-4	6-8	8-10	10-12	13-15	15 + 3 for every additional 500 cubic yards

Specific considerations for biasing sample locations are described in detail in Section 1.2.1 of the tabbed section titled, “Sampling Strategies” under *FACILITY* characterization. The fundamental approaches for biasing sample location are basically the same; however, the biased sampling is now focused on waste characterization.

2.2 Statistical Sampling

Statistical sampling, also referred to as unbiased or probabilistic sampling, is based on the theory of *RANDOM* chance probabilities in order to choose samples which are representative of a given area or volume. The probability of selecting any sampling location is equal. Because sampler bias is not of concern, the error in data accuracy of a *RANDOM* sampling scheme can be objectively measured. Furthermore, knowledge of the waste distribution is not always necessary depending on the purpose for collecting samples.

In some cases it is preferable to choose statistical sampling strategies over biased sampling strategies since they can be used to produce increased data accuracy while eliminating sampler bias. This will depend on the amount of available information with which to bias sampling. In some cases, a combination of approaches will yield the most comprehensive information.

Several statistical sampling strategies can be used to produce an unbiased, representative sampling program. The principles behind the three basic types of *RANDOM* sampling and the situations for which they are best suited are described below. To achieve true *RANDOM* sampling, composite sampling is not acceptable.

1. ***Simple RANDOM sampling*** is a method that requires little or no prior knowledge of material distribution. It relies on *RANDOM* chance probability theory – where each sampling location has an equal and known probability of being selected. In this way, sampling error can be accurately estimated. Often, the area of interest is sectioned into a two- or three-dimensional grid pattern and *RANDOM* coordinates are chosen for sampling.

2. ***Systematic RANDOM sampling*** is an extension of simple *RANDOM* sampling that may produce a more efficient sampling survey. It can be more efficient by reducing the sampling error while maintaining the sample number, or by reducing the number of samples needed to achieve a specified sampling error, or by reducing the cost of collection. This method also requires little or no knowledge about the waste distribution, but bias and imprecision can be introduced if unseen trends or cycles exist. Two methods used to select sample locations under this method follow.

    A) *RANDOMLY* select a transect or transects and sample at pre-selected intervals.

    B) Pre-select both the transect or transects and the sampling interval and starting from a *RANDOMLY* selected point. This is the method used most throughout this chapter.

3. ***Stratified RANDOM sampling*** requires some knowledge about the waste distribution. When stratification is known or suspected, sampling efficiency can be improved by dividing the material into strata that are more homogeneous than the total area. Simple or systematic *RANDOM* sampling techniques can then be used to sample each stratum independently. Each stratum is divided into a grid pattern and the sampling points are selected *RANDOMLY*. If the area is vertically stratified, the sampling points in each stratum are selected *RANDOMLY* and then selected depths are sampled. If the area is horizontally stratified, the sampling points within each stratum are selected *RANDOMLY*, but the total depth is sampled. An analysis of variance (ANOVA) may be done on the analytical results to determine if the strata differ significantly. This can help evaluate whether use of stratified *RANDOM* sampling was necessary and statistically valid. When the volumes of the strata differ or the number of samples within each stratum differs, the results must be weighed appropriately to avoid bias if the data are to be combined in order to draw conclusions.

Of these methods, Systematic *RANDOM* sampling is generally recommended. This approach is often the most efficient since it involves collection of samples at equal intervals, simplifying the collection of samples. Furthermore, systematic *RANDOM* sampling can serve many purposes. When samples are collected on a regular grid interval, conclusions can be drawn about the size of a *HOT SPOT* likely to be identified (or missed), as described in Section 2.1 of the tabbed section titled, “Sampling Strategies.” Furthermore, because the sampling locations are *RANDOMIZED* through systematic *RANDOM* sampling (i.e., by *RANDOMLY* selecting transects and/or the initial

sampling point), it may be appropriate to include the analytical results in a statistical analysis for the purpose of comparison to regulatory thresholds. However, the considerations described in Section 3.2 of this tabbed section must first be addressed.

The number of samples needed to conduct a statistical evaluation will depend on the volume of the material being characterized and the homogeneity of the material. In all cases, a population sufficiency test must be completed and passed to satisfy the number of samples required for the statistical test used. See Section 4.0 of this tabbed section and Section 3.2 of the tabbed section titled, “Statistical Methods.”

For further discussion on sampling strategies and sample collection methods, see "Test Methods for Evaluating Solid Waste," SW846 Volume II: Field Methods, November 1986, Third Edition, USEPA.

2.2.1 Sampling a Process Stream

As noted in Section 2.1.1, process wastes are commonly sampled at the point of generation. This is the preferred method, since it is most representative of the material under study. The lack of exposure to elements that might cause chemical degradation and/or leaching will result in material most indicative of actual conditions. A sampling point along the material conveyor that can be fairly easily and safely reached should be chosen. It should be in an area where the entire belt can be accessed for sampling.

When statistical sampling is conducted to reflect temporal rather than spatial variability, time strata should be established over the course of the process day. The time strata should be established to account for process variability. Ideally, the entire active time of the line should be included in the sampling scheme. Once time strata are chosen, *RANDOM* numbers can be selected to establish sampling times. When the appropriate sampling time arrives, the identified material would be collected.

For example, in a four hour period, a point somewhere on the table would be chosen and numbers greater than 0 but less than 240 would be selected until the number of samples for that strata were obtained. The *RANDOM* numbers would represent time in minutes. These numbers would be added to the starting time for each stratum to determine the time of sampling.

The Microsoft Excel function =RANDBETWEEN(L,U) can be used to select a *RANDOM* number between a specified range of numbers where L is the lower bound of the range and U is the upper bound. In the example above, the function =RANDBETWEEN(0,240) would be used.

If the time strata chosen are of unequal lengths, the number of samples chosen from any one stratum should reflect the percentage contribution that stratum makes to the time frame as a whole. If, for example, a 24 hour operating time is divided such that stratum one is four hours and stratum two is eight hours, stratum two should have twice as many samples as stratum one.

When the appropriate sampling time arrives, the material from the conveyor belt point that had been identified would be sampled.

2.2.2 Sampling Ex Situ/Waste Piles

This section assumes that an adequate investigation has been completed and the volume of the material to be characterized has been confirmed to represent a single, homogeneous population

that can be described by a single statistical distribution (e.g., a normal distribution with a mean of 3.6 and a standard deviation of 0.78).

Samples collected from a waste pile or some ex situ soils may need to be located using a three dimensional gridding method. Characterizations involving soils, piles and/or wastes with a significant vertical component should be evaluated in **three dimensions** (volume evaluation). Examples of such characterizations would be ex situ soil characterization or waste pile characterization involving several cubic feet of soil and/or waste. A grid would be superimposed on the area and a vertical component added at each node.

Establishing Grid Intervals

Statistical sampling strategies often employ the use of gridding to facilitate the unbiased selection of sampling points and the use of accepted statistical tools for evaluating the resultant data.

The equations and tables provided in Section 2.2.1.2 of the tabbed section titled, "Sampling Strategies" can be used to identify grid intervals. Use of these methods facilitate unbiased selection of sampling points and sample coverage proportional to the area of the pile or material being characterized. Other methods can be *PROPOSED* for DEQ approval.

Sampling of the Grid

A minimum of nine samples or 25%, whichever is greater, of the total grid stations should be sampled and analyzed initially to allow a large enough data pool for the statistical analysis. Extra samples should be taken and kept under proper chain of custody and handling procedures at the time of initial sampling. If the statistical analysis indicates that two or three more samples are needed, an additional trip to the field may not be necessary. This may also avoid the need to reestablish the grid pattern at a later date.

Stratified *RANDOM* Sampling

Stratified *RANDOM* Sampling requires some knowledge about the waste distribution. When stratification is known or suspected, sampling efficiency can be improved by dividing the material into strata that are more homogeneous than the total area. Simple or systematic *RANDOM* sampling techniques can then be used to sample each stratum independently.

If the area is vertically stratified, the sampling points in each stratum are selected *RANDOMLY* and then selected depths are sampled. Typically, layers in a stratified material will be between two and five feet thick. Any material over five feet thick must be vertically (as well as horizontally) sampled.

If the area is horizontally stratified, the sampling points within each stratum should be selected *RANDOMLY*, but the total depth sampled. An analysis of variance (ANOVA) may be done on the analytical results to determine if the strata differ significantly. This would assure that the use of stratified *RANDOM* sampling was statistically valid. When the volume of the strata differs or the number of samples within each stratum differs, the results must be weighed appropriately to avoid bias.

3.0 COMPARISON TO REGULATORY THRESHOLDS

Regulatory thresholds for solid waste characterization are found in R 299.4115. Regulatory thresholds for the hazardous waste toxicity characteristic characterization are found in

Part 111 R 299.9217. To determine if environmental media contain a listed hazardous waste, characterization data should be compared to the Type B criteria under the NREPA as found in MERA Memo 8: Revision 3.

3.1 Comparing Characterization Data to Regulatory Thresholds on a Point-by-Point Basis

Analytical data generated using biased sampling strategies must generally be compared to regulatory thresholds on a point-by-point basis. If all samples are below the regulatory threshold and sampling of the waste materials is believed to be adequately representative, no additional samples are warranted. Adequate documentation of all sample locations must be provided based on sufficient knowledge of the waste materials.

If one or more samples contain contaminant concentrations above regulatory thresholds, additional sampling may be necessary to better understand the exceedance (e.g., if the waste materials were expected to be homogeneous and no exceedances were expected), and possibly a change in sampling strategy from biased to statistical. Vertical and horizontal delineation of elevated concentrations in the area of the biased sample location may be necessary.

Statistical analyses of data from biased sampling is generally not appropriate. This is due to the underlying assumptions of most statistical methods used to compare *FACILITY* data to cleanup criteria. One underlying assumption is that the data being evaluated were obtained through *RANDOM* sampling of a single population that can be described by a single statistical distribution (e.g., a normal distribution with a mean of 3.6 and a standard deviation of 0.78).

However, if statistical sampling is completed, use of a statistical analysis to compare characterization data to regulatory thresholds may be appropriate. It is first necessary to evaluate the considerations described below in Section 3.2.

3.2 Comparing Characterization Data to Regulatory Thresholds Using Statistics

Before assembling a data set and conducting a statistical analysis, it is important to give careful consideration to the following:

Population to be sampled

Adequate knowledge of contaminant distribution and the presence of *HOT SPOTS* is essential due to assumptions underlying the statistical methods used to compare characterization data to regulatory thresholds (i.e., 95% UCLs for the mean concentration). Adherence to these assumptions is necessary if an accurate statistical conclusion is to be drawn. One key assumption is that the data are independently and identically distributed (iid). For this assumption to be true, the following are generally necessary:

- Samples must be *independent* and representative of the area included in the analysis. In statistical terms, this means that the data were collected *RANDOMLY*.

- For the data to be identically distributed, each data point must have been drawn from the same *identical* statistical distribution (e.g., a normal distribution with a mean of 3.6 ppm and a standard deviation of 0.78 ppm). Data from a *HOT SPOT* area would be represented by a different statistical distribution than data from non-*HOT SPOT* areas. In

other words, the mean concentration in a *HOT SPOT* area would be higher than in the non-*HOT SPOT* areas and the standard deviation would likely differ as well.

Consequently, identification of *HOT SPOTS* is necessary before an appropriate statistical analysis can be conducted.

Once defined, *HOT SPOTS* should not be included in a statistical analysis for comparison to regulatory thresholds. *HOT SPOTS* must be characterized separately. This is necessary to avoid combining data from different statistical distributions and violating the assumptions of the statistical methods.

Selecting the Appropriate Statistical Method for Comparison to Criteria

A UCL for the mean should be utilized to compare characterization data to regulatory thresholds. Various methods are available for calculating UCLs for the mean concentration. These methods are presented in Chapter 3 of the tabbed section titled, "Statistical Methods."

Selection of the appropriate method for calculating a UCL for the mean requires an evaluation of the assumptions underlying each method. One of these assumptions is the statistical distribution of the data set (i.e., normal, lognormal, or neither). Consequently, each data set must be evaluated for the best-fitting statistical distribution. Chapter 1 of the tabbed section titled, "Statistical Methods" provides several techniques to accomplish this task. As described in Chapter 1, these techniques should be used in combination to best evaluate the statistical distribution.

Chapter 2 of the tabbed section titled, "Statistical Methods" provides techniques for identifying whether suspect data points are statistical outliers. Recommendations for treatment of outliers, once identified, are also provided in Chapter 2.

For the purpose of hazardous waste determinations, a 10% level of significance ($\alpha = 0.10$) may be used. For solid waste determinations, a significance level of 5% ($\alpha = 0.05$) must be used.

4.0 STATISTICAL VALIDATION

It is suggested that a minimum of one sample be collected for any container (55 gallon drum or smaller). A minimum of nine *RANDOMLY* located, discrete samples should be collected per layer/stratification for waste piles or ex situ material if statistics are to be used to compare characterization data to regulatory thresholds. The rationale for this minimum number of samples is described in Section 1.3 of the tabbed section titled, "Statistical Methods."

Further evaluation of the sample size used for waste characterization must be conducted on the data to show that a sufficient number of samples had been collected to use the chosen statistical method. Section 3.2 of the tabbed section titled, "Statistical Methods" provides statistical methods to address this issue, including the Lambda Test.

ACRONYMS / GLOSSARY

Tab 9.0 Acronyms / Glossary

ACRONYMS

ANOVA	Analysis of Variance
BCCs	Bioaccumulative Contaminants of Concern
BEA	Baseline Environmental Assessment
CCTM	Cleanup Criteria Training Material
CFR	Code of Federal Regulations
Csat	Soil Saturation Concentration
CV	Coefficient of Variation
DCC	Direct Contact Criteria
DNAPL	Dense Non-Aqueous Phase Liquids
DWC	Drinking Water Criteria
EU	Exposure Units
FIELDS	Fully-Integrated Environmental Location Decision Support
GCC	Groundwater Contact Criteria
GI	Grid Interval
GNP	Generally Not Practical
GPS	Global Positioning System
GSI	Groundwater Surface Water Interface
GVIIC	Groundwater Volatilization to Indoor Air Inhalation Criteria
IQR	Interquartile Range
LCL	Lower Confidence Limit
Ln	Log-transformed
MBSS	Michigan Background Soil Survey
MERA	Michigan Environmental Response Act
MDEQ (DEQ)	Michigan Department of Environmental Quality
MDNR (DNR)	Michigan Department of Natural Resources
MZB	Mixing Zone-Based
NDs	Non-Detects
NREPA	Natural Resources and Environmental Protection Act
ppb	parts per billion
PSIC	Particulate Soil Inhalation Criteria
RME	Reasonable Maximum Exposure
RCRA	Resource Conservation and Recovery Act

SF	Shapiro-Francia
S^3TM	Sampling Strategies and Statistics Training Materials
SVIIC	Soil Volatilization to Indoor Air Inhalation Criteria
SW	Shapiro-Wilk
TCE	Trichloroethene
U.S.EPA (EPA)	United States Environmental Protection Agency
UCL	Upper Confidence Limit
UTL	Upper Tolerance Limit
VSIC	Volatile Soil Inhalation Criteria
VSP	Visual Sampling Plan
VSR	Verification of Soil Remediation
WET	Whole Effluent Toxicity

GLOSSARY

AVERAGING AREA: The cross sectional area of the contaminated plume used to estimate the discharge rate of venting groundwater in the request for a mixing zone determination, generally the cross sectional area with concentrations greater than the generic GSI criterion.

***BACKGROUND*:** The concentration or level of a hazardous substance which exists in the environment at or regionally proximate to a site that is not attributable to any release at or regionally proximate to the site. [See Statistical Guidesheet 10 for information on each type of *BACKGROUND* described below.

> ***STATEWIDE DEFAULT BACKGROUND*:** The concentrations provided in the September 30, 1993, Michigan Environmental Response Act (MERA) Operational Memorandum #15: Default Type A Cleanup Criteria (Op Memo #15) which represent acceptable *BACKGROUND* concentrations at all *FACILITIES*. [See Appendix A and Chapter 4 of the tabbed section titled, "Statistical Methods."]
>
> ***FACILITY-SPECIFIC BACKGROUND:*** The *BACKGROUND* concentrations in soil at or adjacent to a *FACILITY*. According to Op Memo #15, it is acceptable to establish *BACKGROUND* concentrations higher than the *STATEWIDE DEFAULT BACKGROUND* concentrations for a *FACILITY*. [See Chapter 4 of the tabbed section titled, "Statistical Methods."]
>
> ***REGIONAL BACKGROUND:*** The *BACKGROUND* concentrations in soil that are found regionally proximate to a *FACILITY*. According to Op Memo #15, use of regionally proximate background values higher than the *STATEWIDE DEFAULT BACKGROUND* concentrations may be established for a *FACILITY*. *REGIONAL BACKGROUND* values must be *PROPOSED* on a case-by-case basis.
>
> ***NON-RELEASE ANTHROPOGENIC BACKGROUND:*** *BACKGROUND* concentrations that are affected by anthropogenic compounds which are excluded from the definition of a *RELEASE (*e.g., compounds present in the soil resulting from historic widespread application of pesticides for insect control if applied in accordance with label directions).

***EMISSION SOURCE SIZE/EMISSION SOURCE AREA*:** A term specific to the generic soil inhalation criteria for ambient air that is defined as the horizontal and vertical extent of soil contamination with detectable concentrations.

***EXPOSURE UNIT*:** The area over which an individual is expected to move *RANDOMLY*, such that equivalent amounts of time are assumed to be spent at each location. This area should be logical and generally regular in shape.

FACILITY: Any area, place, or property where a hazardous substance is in excess of the concentrations which satisfy the requirements of Section 20120a(1)(a) or (17) of the cleanup criteria for unrestricted residential use under Part 213, Leaking Underground Storage Tanks, of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended (NREPA), has been *RELEASED*, deposited, disposed of, or otherwise comes to be located. *FACILITY* does not include any area, place, or property at which response activities have been completed which satisfy the cleanup criteria for the residential category provided for in Section 20120a(1)(a) and (17) or at which corrective action has been completed under Part 213 which satisfies the cleanup criteria for unrestricted residential use.

***FACILITY-SPECIFIC BACKGROUND*:** See *BACKGROUND* definition.

GSI MONITORING WELLS: Vertical wells placed along and near the surface water body, no closer than the ordinary high water mark, that are used to monitor groundwater venting to surface water.

***HOT SPOT*:** Two or more adjacent sample locations in reasonably close proximity at which concentrations are sufficiently above cleanup criteria and sample concentrations from the surrounding area (i.e., spatially correlated concentrations sufficiently above criteria) to indicate that they: 1) represent a different statistical population, and 2) pose a potential risk that should not be masked by a statistical analysis. Judgment must be used to determine whether concentrations are sufficiently above cleanup criteria and surrounding location. [See Section 2.2.1.1 of the tabbed section titled, "Sampling Strategies."]

***INTERIM RESPONSES*:** Cleanup or removal of hazardous substances from the environment or performing other actions prior to the selection of a remedial action that is necessary to prevent, minimize, or mitigate injury to the public health, safety, or welfare, the environment, or natural resources, which injury might otherwise result from a release of a hazardous substance.

NON-RELEASE ANTHROPOGENIC BACKGROUND: See *BACKGROUND* definition.

***ONE ACUTE TOXIC UNIT*:** A value calculated as $100/LC_{50}$, where the LC_{50} is determined from a whole effluent toxicity (WET) test which produces a result that is statistically or graphically estimated to be lethal to 50% of the test organisms.

PROPOSAL/PROPOSE/ PROPOSED: A plan describing the use and, in some cases, justifying the applicability of statistics under the Part 201 program. *PROPOSALS* will typically be submitted for the following:

1. comparison of *FACILITY* data to Part 201 cleanup criteria,
2. development of *REGIONAL BACKGROUND* concentrations, or
3. use of statistical methods not described in the tabbed section titled, "Statistical Methods."

PROPOSALS are necessary only if departmental approval is being sought for a response activity. Self-implemented approaches using statistics to support determinations must be documented in a manner that address the three objectives described in the tabbed section titled, "Introduction."

PROPOSALS for comparison of *FACILITY* data to Part 201 cleanup criteria must include a justification for the use of statistics for this purpose that addresses the issues described in the Statistical Guidesheet corresponding to the pathway/condition. These issues generally relate to the practicality of obtaining enough data within limited areas and/or the complexity of the pathway/condition considering contaminant distribution and transport to the point of exposure. These proposals must also include a description of the statistical methods to be used in the analysis and the basis for their selection (e.g., consideration of the appropriate statistical distribution and proportion of concentrations below the detection limit).

PROPOSALS for development of *REGIONAL BACKGROUND* concentrations must include a description of the *REGIONAL BACKGROUND* data to be used as well as the statistical method to be used to develop the *REGIONAL BACKGROUND* concentrations.

PROPOSALS for the use of statistical methods not described in the tabbed section titled, "Statistical Methods" must provide a basis for use of the alternative methods (e.g., consideration of the appropriate statistical distribution and proportion of concentrations below the detection limit) as well as a reference for the alternative method and/or the actual document. Consultation with a professional statistician is advised.

RANDOM/RANDOMIZATION/RANDOMIZED/RANDOMIZING/RANDOMLY: A method utilized to sample *EXPOSURE UNITS*, excluding areas identified as *HOT SPOTS*, such that each location in the *EXPOSURE UNIT* has an equal likelihood of being sampled. [See Section 2.4.2 of the tabbed section titled, "Sampling Strategies."]

REGIONAL BACKGROUND: See *BACKGROUND* definition.

RELEASE: Part 201 Section 1(bb) states in part: "*RELEASE*" includes, but is not limited to, any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing of a hazardous substance into the environment, or the abandonment or discarding of barrels, containers, and other closed receptacles containing a hazardous substance. For exceptions to this definition, see Part 201 Section 1(bb).

REPRESENTATIVE CONCENTRATION: The concentration of a hazardous substance derived from a statistical analysis of *FACILITY* data obtained from sample locations representing: 1) the exposure pathway and land use category in question and 2) contaminant concentrations within a specified *EXPOSURE UNIT*. *RANDOM* sampling within the *EXPOSURE UNIT* (or other area for pathway conditions without default *EXPOSURE UNITS*) is necessary to obtain unbiased, representative samples; however, biased samples collected for the purpose of site characterization may be used in some circumstances, as described in Section 2.4.2 of the tabbed section titled, "Sampling Strategies."

SOURCE SIZE MODIFIER: A multiplier for adjusting the generic soil inhalation criteria for ambient air to correspond to the *EMISSION SOURCE SIZE/EMISSION SOURCE AREA* determined for the *FACILITY*.

***STATEWIDE DEFAULT BACKGROUND*:** See *BACKGROUND* definition.

GLOSSARY OF COMMON STATISTICAL TERMS

μ – Lowercase Greek letter pronounced "mu." Commonly used to represent the population mean of a distribution which, in practice, is usually unknown. The arithmetic mean is an estimate of μ.

σ^2 – Lowercase Greek letter sigma, squared. Commonly used to represent the population variance. The variance describes the width or spread of a distribution and is usually unknown. The sample variance, s^2, is an estimate of σ^2.

σ – Lowercase Greek letter sigma. Commonly used to representthe population standard deviation, the square root of σ^2. The standard deviation is also a measure of the width or spread of a distribution and is usually unknown. The sample standard deviation, *s*, is an estimate of σ.

Bias – the amount by which an estimate differs from the "true" parameter value.

Censored – an observation without a definitive quantity associated with it. In contaminant monitoring, typically reported as an observation below some threshold detection limit (e.g., <7 ppb).

Confidence interval – an interval used to describe the uncertainty associated with a parameter of interest. It is calculated from the sample observations and believed to contain the true parameter value a particular percentage of the time (commonly 95%).

Distribution – a function describing the probability associated with obtaining a measurable quantity of interest.

Interval estimate – two estimated values used to construct an interval, which is intended to enclose a parameter of interest. Values within the interval represent possible values for the parameter of interest.

Lognormal – a distribution characterized by a left-skewed peak and a long right tail. The shape of the distribution depends on the parameters for μ and σ^2. The natural logarithms of observations from a lognormal distribution are normally distributed. The mean and median are generally not the same for a lognormal distribution. The lognormal distribution ranges in value from 0 to $+\infty$.

Mean – the average value of a population.

Median – the "middle" value of a population. Half the population is above the median and half is below.

Normal – a symmetric, bell-shaped, probability distribution. The shape and position of the distribution depends on the parameters for μ and σ^2. Many statistical methods rely upon having normally-distributed data. The mean and median for a normal distribution are the same. The normal distribution ranges in value from $-\infty$ to $+\infty$.

Outlier – a value that has been determined to be inconsistent with an assumed distribution as determined based on the remaining data using statistical methods described in Section 2.1 of Statistical Methods. Values identified as outliers must be evaluated before determining a course of action regarding treatment of the outlier.

Point estimate – a single value, or point, that estimates a parameter of interest. For example, $\bar{x}$ is a point estimate of μ.

Potential outlier – a value that has been identified through the screening measures described in Section 2.1 of Statistical Methods. A values identified as a potential outlier must be further evaluated through formal testing before classifying it as an outlier.

Prediction interval – an interval used to describe the uncertainty associated with obtaining a single new observation.

Skewness – the amount by which a distribution is shifted away from symmetry. For example, a lognormal distribution is typically a positively-skewed (or right-skewed with a long right tail) distribution in which the median is less than the mean.

Transform – a technique for changing the scale and range of data by the application of some function to obtain better statistical properties. For example, to satisfy a method's assumption of normality, the natural log transform is often applied to lognormal data to obtain a normally distributed data set.

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Tab 10.0

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Tab A.0

Appendices

APPENDICES – REFERENCE MATERIALS

A. EPA GUIDANCE FOR DATA QUALITY ASSESSMENT, PRACTICAL METHODS FOR DATA ANALYSIS, EPA QA/G-9, QA00 UPDATE, JULY 2000

METHOD FOR DOUBLE LINEAR INTERPOLATION

SECTION 3.3: TESTS FOR COMPARING TWO POPULATIONS

SECTION 3.3.1: COMPARING TWO MEANS

SECTION 3.3.3: NONPARAMETRIC COMPARISONS OF TWO POPULATIONS

SECTION 4.5.4: LEVENE'S TEST FOR THE EQUALITY OF TWO OR MORE VARIANCES

B. MERA OPERATIONAL MEMORANDUM #15: DEFAULT TYPE A CLEANUP CRITERIA, SEPTEMBER 30, 1993

United States
Environmental Protection
Agency

Office of Environmental
Information
Washington, DC 20460

EPA/600/R-96/084
July, 2000

Guidance for Data Quality Assessment

Practical Methods for Data Analysis

EPA QA/G-9

QA00 UPDATE

Quality

FOREWORD

This document is the 2000 (QA00) version of the *Guidance for Data Quality Assessment* which provides general guidance to organizations on assessing data quality criteria and performance specifications for decision making. The Environmental Protection Agency (EPA) has developed a process for performing Data Quality Assessment (DQA) Process for project managers and planners to determine whether the type, quantity, and quality of data needed to support Agency decisions has been achieved. This guidance is the culmination of experiences in the design and statistical analyses of environmental data in different Program Offices at the EPA. Many elements of prior guidance, statistics, and scientific planning have been incorporated into this document.

This document is distinctly different from other guidance documents; it is not intended to be read in a linear or continuous fashion. The intent of the document is for it to be used as a "tool-box" of useful techniques in assessing the quality of data. The overall structure of the document will enable the analyst to investigate many different problems using a systematic methodology.

This document is one of a series of quality management guidance documents that the EPA Quality Staff has prepared to assist users in implementing the Agency-wide Quality System. Other related documents include:

EPA QA/G-4	*Guidance for the Data Quality Objectives Process*
EPA QA/G-4D	*DEFT Software for the Data Quality Objectives Process*
EPA QA/G-4HW	*Guidance for the Data Quality Objectives Process for Hazardous Waste Site Investigations*
EPA QA/G-9D	*Data Quality Evaluation Statistical Toolbox (DataQUEST)*

This document is intended to be a "living document" that will be updated periodically to incorporate new topics and revisions or refinements to existing procedures. Comments received on this 2000 version will be considered for inclusion in subsequent versions. Please send your written comments on *Guidance for Data Quality Assessment* to:

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Box 4-31: Double Linear Interpolation

The details of the double linear interpolation are provided to assist in the use of Table A-10 of Appendix A. The desired value for $\hat{\lambda}$ corresponds to $\gamma = 0.083$ and, $h = 0.125$ from Box 4-30, Step 3. The values from Table A-10 for interpolatation are:

γ	$h = 0.10$	$h = 0.15$
0.05	0.11431	0.17925
0.10	0.11804	0.18479

There are 0.05 units between 0.10 and 0.15 on the h-scale and 0.025 units between 0.10 and 0.125. Therefore, the value of interest lies (0.025/0.05)100% = 50% of the distance along the interval between 0.10 and 0.15. To linearly interpolate between tabulated values on the h axis for $\gamma = 0.05$, the range between the values must be calculated, 0.17925 - 0.11431 = 0.06494; the value that is 50% of the distance along the range must be computed, 0.06494 x 0.50 = 0.03247; and then that value must be added to the lower point on the tabulated values, 0.11431 + 0.03247 = 0.14678. Similarly for $\gamma = 0.10$, 0.18479 - 0.11804 = 0.06675, 0.06675 x 0.50 = 0.033375, and 0.11804 + 0.033375 = 0.151415.

On the γ-axis there are 0.033 units between 0.05 and 0.083 and there are 0.05 units between 0.05 and 0.10. The value of interest (0.083) lies (0.033/0.05 x 100) = 66% of the distance along the interval between 0.05 and 0.10, so 0.151415 - 0.14678 = 0.004635, 0.004635 * 0.66 = 0.003059. Therefore,

$$\hat{\lambda} = 0.14678 + 0.003059 = 0.149839.$$

4.7.2.2 Trimmed Mean

Trimming discards the data in the tails of a data set in order to develop an unbiased estimate of the population mean. For environmental data, nondetects usually occur in the left tail of the data so trimming the data can be used to adjust the data set to account for nondetects when estimating a mean. Developing a 100p% trimmed mean involves trimming p% of the data in both the lower and the upper tail. Note that p must be between 0 and .5 since p represents the portion deleted in both the upper and the lower tail. After np of the largest values and np of the smallest values are trimmed, there are n(1-2p) data values remaining. Therefore, the proportion trimmed is dependent on the total sample size (n) since a reasonable amount of samples must remain for analysis. For approximately symmetric distributions, a 25% trimmed mean (the midmean) is a good estimator of the population mean. However, environmental data are often skewed (non-symmetric) and in these cases a 15% trimmed mean performance may be a good estimator of the population mean. It is also possible to trim the data only to replace the nondetects. For example, if 3% of the data are below the detection limit, a 3% trimmed mean could be used to estimate the population mean. Directions for developing a trimmed mean are contained in Box 4-32 and an example is given in Box 4-33. A trimmed variance is rarely calculated and is of limited use.

4.7.2.3 Winsorized Mean and Standard Deviation

Winsorizing replaces data in the tails of a data set with the next most extreme data value. For environmental data, nondetects usually occur in the left tail of the data. Therefore, winsorizing can be used to adjust the data set to account for nondetects. The mean and standard deviation can then be computed on the new data set. Directions for winsorizing data (and revising the sample size) are contained in Box 4-34 and an example is given in Box 4-35

TABLE A-10: VALUES OF THE PARAMETER $\hat{\lambda}$ FOR COHEN'S ESTIMATES ADJUSTING FOR NONDETECTED VALUES

γ	h .01	.02	.03	.04	.05	.06	.07	.08	.09	.10	.15	.20
.00	.010100	.020400	.030902	.041583	.052507	.063625	.074953	.08649	.09824	.11020	.17342	.24268
.05	.010551	.021294	.032225	.043350	.054670	.066159	.077909	.08983	.10197	.11431	.17925	.25033
.10	.010950	.022082	.033398	.044902	.056596	.068483	.080563	.09285	.10534	.11804	.18479	.25741
.15	.011310	.022798	.034466	.046318	.058356	.070586	.083009	.09563	.10845	.12148	.18985	.26405
.20	.011642	.023459	.035453	.047829	.059990	.072539	.085280	.09822	.11135	.12469	.19460	.27031
.25	.011952	.024076	.036377	.048858	.061522	.074372	.087413	.10065	.11408	.12772	.19910	.27626
.30	.012243	.024658	.037249	.050018	.062969	.076106	.089433	.10295	.11667	.13059	.20338	.28193
.35	.012520	.025211	.038077	.051120	.064345	.077736	.091355	.10515	.11914	.13333	.20747	.28737
.40	.012784	.025738	.038866	.052173	.065660	.079332	.093193	.10725	.12150	.13595	.21129	.29250
.45	.013036	.026243	.039624	.053182	.066921	.080845	.094958	.10926	.12377	.13847	.21517	.29765
.50	.013279	.026728	.040352	.054153	.068135	.082301	.096657	.11121	.12595	.14090	.21882	.30253
.55	.013513	.027196	.041054	.055089	.069306	.083708	.098298	.11208	.12806	.14325	.22225	.30725
.60	.013739	.027849	.041733	.055995	.070439	.085068	.099887	.11490	.13011	.14552	.22578	.31184
.65	.013958	.028087	.042391	.056874	.071538	.086388	.10143	.11666	.13209	.14773	.22910	.31630
.70	.014171	.028513	.043030	.057726	.072505	.087670	.10292	.11837	.13402	.14987	.23234	.32065
.75	.014378	.029927	.043652	.058556	.073643	.088917	.10438	.12004	.13590	.15196	.23550	.32489
.80	.014579	.029330	.044258	.059364	.074655	.090133	.10580	.12167	.13775	.15400	.23858	.32903
.85	.014773	.029723	.044848	.060153	.075642	.091319	.10719	.12225	.13952	.15599	.24158	.33307
.90	.014967	.030107	.045425	.060923	.075606	.092477	.10854	.12480	.14126	.15793	.24452	.33703
.95	.015154	.030483	.045989	.061676	.077549	.093611	.10987	.12632	.14297	.15983	.24740	.34091
1.00	.015338	.030850	.046540	.062413	.078471	.094720	.11116	.12780	.14465	.16170	.25022	.34471

γ	h .25	.30	.35	.40	.45	.50	.55	.60	.65	.70	.80	.90
.00	.31862	.4021	.4941	.5961	.7096	.8388	.9808	1.145	1.336	1.561	2.176	3.283
.05	.32793	.4130	.5066	.6101	.7252	.8540	.9994	1.166	1.358	1.585	2.203	3.314
.10	.33662	.4233	.5184	.6234	.7400	.8703	1.017	1.185	1.379	1.608	2.229	3.345
.15	.34480	.4330	.5296	.6361	.7542	.8860	1.035	1.204	1.400	1.630	2.255	3.376
.20	.35255	.4422	.5403	.6483	.7673	.9012	1.051	1.222	1.419	1.651	2.280	3.405
.25	.35993	.4510	.5506	.6600	.7810	.9158	1.067	1.240	1.439	1.672	2.305	3.435
.30	.36700	.4595	.5604	.6713	.7937	.9300	1.083	1.257	1.457	1.693	2.329	3.464
.35	.37379	.4676	.5699	.6821	.8060	.9437	1.098	1.274	1.475	1.713	2.353	3.492
.40	.38033	.4735	.5791	.6927	.8179	.9570	1.113	1.290	1.494	1.732	2.376	3.520
.45	.38665	.4831	.5880	.7029	.8295	.9700	1.127	1.306	1.511	1.751	2.399	3.547
.50	.39276	.4904	.5967	.7129	.8408	.9826	1.141	1.321	1.528	1.770	2.421	3.575
.55	.39679	.4976	.6061	.7225	.8517	.9950	1.155	1.337	1.545	1.788	2.443	3.601
.60	.40447	.5045	.6133	.7320	.8625	1.007	1.169	1.351	1.561	1.806	2.465	3.628
.65	.41008	.5114	.6213	.7412	.8729	1.019	1.182	1.368	1.577	1.824	2.486	3.654
.70	.41555	.5180	.6291	.7502	.8832	1.030	1.195	1.380	1.593	1.841	2.507	3.679
.75	.42090	.5245	.6367	.7590	.8932	1.042	1.207	1.394	1.608	1.851	2.528	3.705
.80	.42612	.5308	.6441	.7676	.9031	1.053	1.220	1.408	1.624	1.875	2.548	3.730
.85	.43122	.5370	.6515	.7781	.9127	1.064	1.232	1.422	1.639	1.892	2.568	3.754
.90	.43622	.5430	.6586	.7844	.9222	1.074	1.244	1.435	1.653	1.908	2.588	3.779
.95	.44112	.5490	.6656	.7925	.9314	1.085	1.255	1.448	1.668	1.924	2.607	3.803
1.00	.44592	.5548	.6724	.8005	.9406	1.095	1.287	1.461	1.882	1.940	2.626	3.827

The concept of a confidence interval can be shown by a simple example. Suppose a stable situation producing data without any anomalies was sampled many times. Each time the sample was taken, the mean and standard deviation was calculated from the sample and a confidence interval constructed using the method of Box 3-10.

Box 3-12: Directions for a Confidence Interval for a Mean for Simple and Systematic Random Samples

Let $X_1, X_2, ..., X_n$ represent a sample of size n from a population of normally distributed values.

Step 1: Use the directions in Box 2-2 to calculate the sample mean, $\overline{X}$. Use the directions in Box 2-3 to calculate the sample standard deviation, s.

Step 2: Use Table A-1 of Appendix A to find the critical value $t_{1-\alpha/2}$ such that 100(1-α/2)% of the t distribution with n - 1 degrees of freedom is below $t_{1-\alpha/2}$. For example, if α = 0.10 and n = 16, then n-1 = 15 and $t_{1-\alpha/2}$ = 1.753.

Step 3: The (1-α)100% confidence interval is: $\overline{X} - \frac{t_{1-\alpha/2}s}{\sqrt{n}}$ *to* $\overline{X} + \frac{t_{1-\alpha/2}s}{\sqrt{n}}$

Box 3-13: An Example of a Confidence Interval for a Mean for a Random or Systematic Random Samples

The effluent from a discharge point in a plating manufacturing plant was sampled 7 times over the course of 4 days for the presence of Arsenic with the following results: 8.1, 7.9, 7.9. 8.2, 8.2, 8.0,7.9. The directions in Box 3-12 will be used to develop a 95% confidence interval for the mean.

Step 1: Using Box 2-2, $\overline{X}$ =8.03. Use Box 2-3, s=0.138.

Step 2: Using Table A-1 of Appendix A and 6 *degrees of freedom,* $t_{1-\alpha/2}$ = 2.447.

Step 3: The (1-α)100% confidence interval is:

$$8.03 - \frac{2.447x0.138}{\sqrt{7}} \text{ to } 8.03 + \frac{2.447x0.138}{\sqrt{7}} \text{ or 7.902 to 8.158.}$$

3.3 TESTS FOR COMPARING TWO POPULATIONS

A two-sample test involves the comparison of two populations or a "before and after" comparison. In environmental applications, the two populations to be compared may be a potentially contaminated area with a background area or concentration levels from an upgradient and a downgradient well. The comparison of the two populations may be based on a statistical parameter that characterizes the relative location (e.g., a mean or median), or it may be based on a distribution-free comparison of the two population distributions. Tests that do not assume an underlying distributions (e.g., normal or lognormal) are called distribution-free or nonparametric tests. These tests are often more useful for comparing two populations than those that assume a specific distribution because they make less stringent assumptions. Section 3.3.1 covers tests for differences in the means of two populations. Section 3.3.2 covers tests for differences in the

proportion or percentiles of two populations. Section 3.3.3 describes distribution-free comparisons of two populations. Section 3.3.4 describes tests for comparing two medians.

Often, a two-sample test involves the comparison of the difference of two population parameters to a threshold value. For environmental applications, the threshold value is often zero, representing the case where the data are used to determine which of the two population parameters is greater than the other. For example, concentration levels from a Superfund site may be compared to a background site. Then, if the Superfund site levels exceed the background levels, the site requires further investigation. A two-sample test may also be used to compare readings from two instruments or two separate populations of people.

If the exact same sampling locations are used for both populations, then the two samples are not independent. This case should be converted to a one-sample problem by applying the methods described in Section 3.2 to the differences between the two populations at the same location. For example, one could compare contaminant levels from several wells after treatment to contaminant levels from the same wells before treatment. The methods described in Section 3.2 would then be applied to the differences between the before and after treatment contaminant levels for each well.

3.3.1 Comparing Two Means

Let μ_1 represent the mean of population 1 and μ_2 represent the mean of population 2. The hypotheses considered in this section are:

Case 1: H_0: $\mu_1 - \mu_2 \leq \delta_0$ vs. H_A: $\mu_1 - \mu_2 > \delta_0$; and

Case 2: H_0: $\mu_1 - \mu_2 \geq \delta_0$ vs. H_A: $\mu_1 - \mu_2 < \delta_0$.

An example of a two-sample test for population means is comparing the mean contaminant level at a remediated Superfund site to a background site; in this case, δ_0 would be zero. Another example is a Record of Decision for a Superfund site which specifies that the remediation technique must reduce the mean contaminant level by 50 ppm each year. Here, each year would be considered a separate population and δ_0 would be 50 ppm.

The information required for these tests includes the null and alternative hypotheses (either Case 1 or Case 2); the gray region (i.e., a value $\delta_1 > \delta_0$ for Case 1 or a value $\delta_1 < \delta_0$ for Case 2 representing the bound of the gray region); the false rejection error rate α at δ_0; the false acceptance error rate β at δ_1; and any additional limits on decision errors. It may be helpful to label additional false rejection error limits as α_2 at $\delta_{\alpha 2}$, α_3 at $\delta_{\alpha 3}$, etc., and to label additional false acceptance error limits as β_2 at $\delta_{\beta 2}$, β_3 at $\delta_{\beta 3}$, etc.

3.3.1.1 Student's Two-Sample t-Test (Equal Variances)

PURPOSE

Student's two-sample t-test can be used to compare two population means based on the independent random samples $X_1, X_2, \ldots, X_m$ from the first population, and $Y_1, Y_2, \ldots, Y_n$ from the second population. This test assumes the variabilities (as expressed by the variance) of the two populations are approximately equal. If the two variances are not equal (a test is described in Section 4.5), use Satterthwaite's t test (Section 3.3.1.2).

ASSUMPTIONS AND THEIR VERIFICATION

The principal assumption required for the two-sample t-test is that a random sample of size m ($X_1, X_2, \ldots, X_m$) is drawn from population 1, and an independent random sample of size n ($Y_1, Y_2, \ldots, Y_n$) is drawn from population 2. Validity of the random sampling and independence assumptions should be confirmed by reviewing the procedures used to select the sampling points.

The second assumption required for the two-sample t-tests are that the sample means $\overline{X}$ (sample 1) and $\overline{Y}$ (sample 2) are approximately normally distributed. If both m and n are large, one may make this assumption without further verification. For small sample sizes, approximate normality of the sample means can be checked by testing the normality of each of the two samples.

LIMITATIONS AND ROBUSTNESS

The two-sample t-test with equal variances is robust to violations of the assumptions of normality and equality of variances. However, if the investigator has tested and rejected normality or equality of variances, then nonparametric procedures may be applied. The t-test is not robust to outliers because sample means and standard deviations are sensitive to outliers.

SEQUENCE OF STEPS

Directions for the two-sample t-test for a simple random sample and a systematic simple random sample are given in Box 3-14 and an example in Box 3-15.

3.3.1.2 Satterthwaite's Two-Sample t-Test (Unequal Variances)

Satterthwaite's t-test should be used to compare two population means when the variances of the two populations are not equal. It requires the same assumptions as the two-sample t-test (Section 3.3.1.1) except the assumption of equal variances.

Directions for Satterthwaite's t-test for a simple random sample and a systematic simple random sample are given in Box 3-16 and an example in Box 3-17.

Box 3-14: Directions for the Student's Two-Sample t-Test (Equal Variances) for Simple and Systematic Random Samples

This describes the steps for applying the two-sample t-tests for differences between the population means when the two population variances are equal for Case 1 (H_0: $\mu_1 - \mu_2 \leq \delta_0$). Modifications for Case 2
(H_0: $\mu_1 - \mu_2 \geq \delta_0$) are given in parentheses { }.

STEP 1: Calculate the sample mean $\overline{X}$ and the sample variance s_X^2 for sample 1 and compute the sample mean $\overline{Y}$ and the sample variance s_Y^2 for sample 2.

STEP 2: Use Section 4.5 to determine if the variances of the two populations are equal. If the variances of the two populations are not equal, use Satterthwaite's t test (Section 3.3.1.2). Otherwise, compute the pooled standard deviation

$$s_E = \sqrt{\frac{(m-1)s_X^2 + (n-1)s_Y^2}{(m-1)+(n-1)}}.$$

STEP 3: Calculate $t = \dfrac{\overline{X} - \overline{Y} - \delta_0}{s_E\sqrt{1/n + 1/m}}$.

Use Table A-1 of Appendix A to find the critical value $t_{1-\alpha}$ such that 100(1-α)% of the t-distribution with (m+n-2) degrees of freedom is below $t_{1-\alpha}$.

If $t > t_{1-\alpha}$ {$t < -t_{1-\alpha}$}, the null hypothesis may be rejected. Go to Step 5.

If $t \not> t_{1-\alpha}$ {$t \not< -t_{1-\alpha}$}, there is not enough evidence to reject the null hypothesis. Therefore, the false acceptance error rate will need to be verified. Go to Step 4.

STEP 4: To calculate the power of the test, assume that the true values for the mean and standard deviation are those obtained in the sample and use a statistical software package like the DEFT software (EPA, 1994) or the DataQUEST software (EPA, 1996) to generate the power curve of the two-sample t-test. If only one false acceptance error rate (β) has been specified (at δ_1), it is possible to calculate the sample size which achieves the DQOs, assuming the true mean and standard deviation are equal to the values estimated from the sample, instead of calculating the power of the test. Calculate

$$m^* = n^* = \frac{2s^2(z_{1-\alpha} + z_{1-\beta})^2}{(\delta_1 - \delta_0)^2} + (0.25)z_{1-\alpha}^2$$

If $m^* \leq m$ and $n^* \leq n$, the false acceptance error rate has been satisfied. Otherwise, the false acceptance error rate has not been satisfied.

STEP 5: The results of the test could be:

1) the null hypothesis was rejected, and it seems $\mu_1 - \mu_2 > \delta_0$ {$\mu_1 - \mu_2 < \delta_0$};

2) the null hypothesis was not rejected, the false acceptance error rate was satisfied, and it seems $\mu_1 - \mu_2 \leq \delta_0$ {$\mu_1 - \mu_2 \geq \delta_0$}; or

3) the null hypothesis was not rejected, the false acceptance error rate was not satisfied, and it seems $\mu_1 - \mu_2 \leq \delta_0$ {$\mu_1 - \mu_2 \geq \delta_0$}, but this conclusion is uncertain because the sample size

Box 3-15: An Example of a Student's Two-Sample t-Test (Equal Variances) for Simple and Systematic Random Samples

At a hazardous waste site, area 1 (cleaned using an in-situ methodology) was compared with a similar (but relatively uncontaminated) reference area, area 2. If the in-situ methodology worked, then the two sites should be approximately equal in average contaminant levels. If the methodology did not work, then area 1 should have a higher average than the reference area. Seven random samples were taken from area 1, and eight were taken from area 2. Because the contaminant concentrations in the two areas are supposedly equal, the null hypothesis is H_0: $\mu_1 - \mu_2 \leq 0$ (Case 1). The false rejection error rate was set at 5% and the false acceptance error rate was set at 20% (β) if the difference between the areas is 2.5 ppb.

STEP 1:

	Sample Mean	Sample Variance
Area 1	7.8 ppm	2.1 ppm^2
Area 2	6.6 ppm	2.2 ppm^2

STEP 2: Methods described in Section 4.5 were used to determine that the variances were essentially equal. Therefore,

$$s_E = \sqrt{\frac{(7-1)2.1 + (8-1)2.2}{(7-1)+(8-1)}} = 1.4676$$

STEP 3:

$$t = \frac{7.8 - 6.6 - 0}{1.4676\sqrt{1/7+1/8}} = 1.5798$$

Table A-1 of Appendix A was used to find that the critical value $t_{0.95}$ with (7 + 8 - 2) = 13 degrees of freedom is 1.771.

Because $t \not> t_{1-\alpha}$ (i.e., 1.5798 $\not>$ 1.771), there is not enough evidence to reject the null hypothesis. The false acceptance error rate will need to be verified.

STEP 4: Assuming the true values for the mean and standard deviation are those obtained in the sample:

$$m^* = n^* = \frac{2(1.4676^2)(1.645+0.842)^2}{(2.5-0)^2} + (0.25)1.645^2 = 4.938, \text{ i.e., } 5.$$

Because $m^* \leq$ m (7) and $n^* \leq$ n (8), the false acceptance error rate has been satisfied.

STEP 5: The null hypothesis was not rejected and the false acceptance error rate was satisfied. Therefore, it seems there is no difference between the two areas and that the in-situ methodology worked as expected.

Box 3-16: Directions for Satterthwaite's t-Test (Unequal Variances) for Simple and Systematic Random Samples

This describes the steps for applying the two-sample t-test for differences between the population means for Case 1 (H_0: $\mu_1 - \mu_2 \leq \delta_0$). Modifications for Case 2 (H_0: $\mu_1 - \mu_2 \geq \delta_0$) are given in parentheses { }.

STEP 1: Calculate the sample mean $\overline{X}$ and the sample variance s_X^2 for sample 1 and compute the sample mean $\overline{Y}$ and the sample variance s_Y^2 for sample 2.

STEP 2: Using Section 4.5, test whether the variances of the two populations are equal. If the variances of the two populations are not equal, compute:

$$s_{NE} = \sqrt{\frac{s_X^2}{m} + \frac{s_Y^2}{n}}$$

If the variances of the two populations appear approximately equal, use Student's two-sample t-test (Section 3.3.1.1, Box 3-14).

STEP 3: Calculate $t = \dfrac{\overline{X} - \overline{Y} - \delta_0}{s_{NE}}$

Use Table A-1 of Appendix A to find the critical value $t_{1-\alpha}$ such that 100(1-α)% of the t-distribution with f degrees of freedom is below $t_{1-\alpha}$, where

$$f = \frac{\left[\dfrac{s_X^2}{m} + \dfrac{s_Y^2}{n}\right]^2}{\dfrac{s_X^4}{m^2(m-1)} + \dfrac{s_Y^4}{n^2(n-1)}}$$

(Round f down to the nearest integer.)

If $t > t_{1-\alpha}$ {$t < -t_{1-\alpha}$}, the null hypothesis may be rejected. Go to Step 5.

If $t \not> t_{1-\alpha}$ {$t \not< -t_{1-\alpha}$}, there is not enough evidence to reject the null hypothesis and therefore, the false acceptance error rate will need to be verified. Go to Step 4.

STEP 4: If the null hypothesis (H_0) was not rejected, calculate either the power of the test or the sample size necessary to achieve the false rejection and false acceptance error rates. To calculate the power of the test, assume that the true values for the mean and standard deviation are those obtained in the sample and use a statistical software package to generate the power curve of the two-sample t-test. A simple method to check on statistical power does not exist.

STEP 5: The results of the test could be:

1) the null hypothesis was rejected, and it seems $\mu_1 - \mu_2 > \delta_0$ {$\mu_1 - \mu_2 < \delta_0$};

2) the null hypothesis was not rejected, the false acceptance error rate was satisfied, and it seems $\mu_1 - \mu_2 \leq \delta_0$ {$\mu_1 - \mu_2 \geq \delta_0$}; or

3) the null hypothesis was not rejected, the false acceptance error rate was not satisfied, and it seems $\mu_1 - \mu_2 \leq \delta_0$ {$\mu_1 - \mu_2 \geq \delta_0$}, but this conclusion is uncertain because the sample

Box 3-17: An Example of Satterthwaite's t-Test (Unequal Variances) for Simple and Systematic Random Samples

At a hazardous waste site, area 1 (cleaned using an in-situ methodology) was compared with a similar (but relatively uncontaminated) reference area, area 2. If the in-situ methodology worked, then the two sites should be approximately equal in average contaminant levels. If the methodology did not work, then area 1 should have a higher average than the reference area. Seven random samples were taken from area 1, and eight were taken from area 2. Because the contaminant concentrations in the two areas are supposedly equal, the null hypothesis is H_0: $\mu_1 - \mu_2 \leq 0$ (Case 1). The false rejection error rate was set at 5% and the false acceptance error rate was set at 20% (β) if the difference between the areas is 2.5 ppb.

STEP 1:

	Sample Mean	Sample Variance
Area 1	9.2 ppm	1.3 ppm^2
Area 2	6.1 ppm	5.7 ppm^2

STEP 2: Using Section 4.5, it was determined that the variances of the two populations were not equal, and therefore using Satterthwaite's method is appropriate:

$$s_{NE} = \sqrt{1.3/7 + 5.7/8} = 0.9477$$

STEP 3:

$$t = \frac{9.2 - 6.1 - 0}{0.9477} = 3.271$$

Table A-1 was used with f degrees of freedom, where

$$f = \frac{[1.3/7 + 5.7/8]^2}{\frac{1.3^2}{7^2(7-1)} + \frac{5.7^2}{8^2(8-1)}} = 10.307 \ (i.e., \ 10 \ degrees \ of \ freedom)$$

(recall that f is rounded down to the nearest integer), to find $t_{1-\alpha} = 1.812$.

Because $t > t_{0.95}$ (3.271 > 1.812), the null hypothesis may be rejected.

STEP 5: Because the null hypothesis was rejected, it would appear there is a difference between the two areas (area 1 being more contaminated than area 2, the reference area) and that the in-situ methodology has not worked as intended.

3.3.2 Comparing Two Proportions or Percentiles

This section considers hypotheses concerning two population proportions (or two population percentiles); for example, one might use these tests to compare the proportion of children with elevated blood lead in one urban area compared with the proportion of children with elevated blood lead in another area. The population proportion is the ratio of the number of elements in a subset of the total population to the total number of elements, where the subset has some specific characteristic that the rest of the elements do not. A population percentile represents the percentage of elements of a population having values less than some threshold value C.

3.3.3 Nonparametric Comparisons of Two Populations

In many cases, assumptions on distributional characteristics are difficult to verify or difficult to satisfy for both populations. In this case, several distribution-free test procedures are available that compare the shape and location of the two distributions instead of a statistical parameter (such as a mean or median). The statistical tests described below test the null hypothesis "H_0: the distributions of population 1 and population 2 are identical (or, the site is not more contaminated than background)" versus the alternative hypothesis "H_A: part of the distribution of population 1 is located to the right of the distribution of population 2 (or the site is more contaminated than background)." Because of the structure of the hypothesis tests, the labeling of populations 1 and 2 is of importance. For most environmental applications, population 1 is the area of interest (i.e., the potentially contaminated area) and population 2 is the reference area.

There is no formal statistical parameter of interest in the hypotheses stated above. However, the concept of false rejection and false acceptance error rates still applies.

3.3.3.1 The Wilcoxon Rank Sum Test

PURPOSE

The Wilcoxon rank sum test can be used to compare two population distributions based on m independent random samples $X_1, X_2, \ldots, X_m$ from the first population, and n independent random samples $Y_1, Y_2, \ldots, Y_n$ from the second population. When applied with the Quantile test (Section 3.3.3.2), the combined tests are most powerful for detecting true differences between two population distributions.

ASSUMPTIONS AND THEIR VERIFICATION

The validity of the random sampling and independence assumptions should be verified by review of the procedures used to select the sampling points. The two underlying distributions are assumed to have the same shape and dispersion, so that one distribution differs by some fixed amount (or is increased by a constant) when compared to the other distribution. For large samples, to test whether both site distributions have approximately the same shape, one can create and compare histograms for the samples.

LIMITATIONS AND ROBUSTNESS

The Wilcoxon rank sum test may produce misleading results if many data values are the same. When values are the same, their relative ranks are the same, and this has the effect of diluting the statistical power of the Wilcoxon rank sum test. Estimated concentrations should be reported for data below the detection limit, even if these estimates are negative, because their relative magnitude to the rest of the data is of importance. An important advantage of the Wilcoxon rank sum test is its partial robustness to outliers, because the analysis is conducted in

terms of rankings of the observations. This limits the influence of outliers because a given data point can be no more extreme than the first or last rank.

SEQUENCE OF STEPS

Directions and an example for the Wilcoxon rank sum test are given in Box 3-20 and Box 3-21. However, if a relatively large number of samples have been taken, it is more efficient in terms of statistical power to use a large sample approximation to the Wilcoxon rank sum test (Box 3-22) to obtain the critical values of W.

Box 3-20: Directions for the Wilcoxon Rank Sum Test for Simple and Systematic Random Samples

Let $X_1, X_2, \ldots, X_n$ represent the n data points from population 1 and $Y_1, Y_2, \ldots, Y_m$ represent the m data points from population 2 where both n and m are less than or equal to 20. For Case 1, the null hypothesis will be that population 1 is shifted to the left of population 2 with the alternative that population 1 is either the same as or shifted to the right of population 2; Case 2 will be that population 1 is shifted to the right of population 2 with the alternative that population 1 is the same as or shifted to the left of population 2; for Case 3, the null hypothesis will be that there is no difference between the two populations and the alternative hypothesis will be that population 1 is shifted either to the right or left of population 2. If either m or n are larger than 20, use Box 3-22.

STEP 1: List and rank the measurements from both populations from smallest to largest, keeping track of which population contributed each measurement. The rank of 1 is assigned to the smallest value, the rank of 2 to the second smallest value, and so forth. If there are ties, assign the average of the ranks that would otherwise have been assigned to the tied observations.

STEP 2: Calculate R as the sum of the ranks of the data from population 1, then calculate

$$W = R - \frac{n(n+1)}{2}.$$

STEP 3: Use Table A-7 of Appendix A to find the critical value w_α (or $w_{\alpha/2}$ for Case 3). For Case 1, reject the null hypothesis if $W > nm - w_\alpha$. For Case 2, reject the null hypothesis if $W < w_\alpha$. For Case 3, reject the null hypothesis if $W > nm - w_{\alpha/2}$ or $W < w_{\alpha/2}$. If the null hypothesis is rejected, go to Step 5. Otherwise, go to Step 4.

STEP 4: If the null hypothesis (H_0) was not rejected, the power of the test or the sample size necessary to achieve the false rejection and false acceptance error rates should be calculated. For small samples sizes, these calculations are too complex for this document.

STEP 5: The results of the test could be:

1) the null hypothesis was rejected and it seems that population 1 is shifted to the right (Case 1), to the left (Case 2) or to the left or right (Case 3) of population 2.

2) the null hypothesis was not rejected and it seems that population 1 is shifted to the left (Case 1) or to the right (Case 2) of population 2, or there is no difference between the two populations (Case 3).

Box 3-21: An Example of the Wilcoxon Rank Sum Test for Simple and Systematic Random Samples

At a hazardous waste site, area 1 (cleaned using an in-situ methodology) was compared with a similar (but relatively uncontaminated) reference area, area 2. If the in-situ methodology worked, then the two sites should be approximately equal in average contaminant levels. If the methodology did not work, then area 1 should have a higher average than the reference area. The null hypothesis will be that area 1 is shifted to the right of area 2 and the alternative hypothesis will be that there is no difference between the two areas or that area 1 is shifted to the left of area 2 (Case 2). The false rejection error rate was set at 10% and the false acceptance error rate was set at 20% (β) if the difference between the areas is 2.5 ppb. Seven random samples were taken from area 1 and eight samples were taken from area 2:

Area 1	Area 2
17, 23, 26, 5	16, 20, 5, 4
13, 13, 12	8, 10, 7, 3

STEP 1: The data listed and ranked by size are (Area 1 denoted by *):

Data (ppb): 3, 4, 5, 5*, 7, 8, 10, 12*, 13*, 13*, 16, 17*, 20, 23*, 26*
Rank: 1, 2, 3.5, 3.5*, 5, 6, 7, 8*, 9.5*, 9.5* 11, 12*, 13, 14*, 15*

STEP 2: R = 3.5 + 8 + 9.5 + 9.5 + 12 + 14 + 15 = 71..5. W = 71.5 - 7(7 + 1)/2 = 43.5

STEP 3: Using Table A-7 of Appendix A, $\alpha = 0.10$ and $W_{\alpha} = 17$. Since 43.5 > 17, do not reject the null hypothesis.

STEP 4: The null hypothesis was not rejected and it would be appropriate to calculate the probable power of the test. However, because the number of samples is small, extensive computer simulations are required in order to estimate the power of this test which is beyond the scope of this guidance.

STEP 5: The null hypothesis was not rejected. Therefore, it is likely that there is no difference between the investigated area and the reference area, although the statistical power is low due to the small sample sizes involved.

Box 3-22: Directions for the Large Sample Approximation to the Wilcoxon Rank Sum Test for Simple and Systematic Random Samples

Let $X_1, X_2, \ldots, X_n$ represent the n data points from population 1 and $Y_1, Y_2, \ldots, Y_m$ represent the m data points from population 2 where both n and m are greater than 20. For Case 1, the null hypothesis will be that population 1 is shifted to the left of population 2 with the alternative that population 1 is the same as or shifted to the right of population 2; for Case 2, the null hypothesis will be that population 1 is shifted to the right of population 2 with the alternative that population 1 is the same as or shifted to the left of population 2; for Case 3, the null hypothesis will be that there is no difference between the populations and the alternative hypothesis will be that population 1 is shifted either to the right or left of population 2.

STEP 1: List and rank the measurements from both populations from smallest to largest, keeping track of which population contributed each measurement. The rank of 1 is assigned to the smallest value, the rank of 2 to the second smallest value, and so forth. If there are ties, assign the average of the ranks that would otherwise have been assigned to the tied observations.

STEP 2: Calculate W as the sum of the ranks of the data from population 1.

STEP 3: Calculate $w_p = \frac{mn}{2} + Zp\sqrt{mn(n + m + 1)/12}$ where p = 1 - α for Case 1, p = α for Case 2, and z_p is the p^{th} percentile of the standard normal distribution (Table A-1 of Appendix A). For Case 3, calculate both $w_{\alpha/2}$ (p = α/2) and $w_{1-\alpha/2}$ (p = 1 - α/2).

STEP 4: For Case 1, reject the null hypothesis if $W > w_{1-\alpha}$. For Case 2, reject the null hypothesis if $W < w_{\alpha}$. For Case 3, reject the null hypothesis if $W > w_{1-\alpha/2}$ or $W < w_{\alpha/2}$. If the null hypothesis is rejected, go to Step 6. Otherwise, go to Step 5.

STEP 5: If the null hypothesis (H_0) was not rejected, calculate either the power of the test or the sample size necessary to achieve the false rejection and negative error rates. If only one false acceptance error rate (β) has been specified (at δ_1), it is possible to calculate the sample size that achieves the DQOs, assuming the true mean and standard deviation are equal to the values estimated from the sample, instead of calculating the power of the test. If m and n are large, calculate:

$$m^* = n^* = \frac{2s^2(z_{1-\alpha} + z_{1-\beta})^2}{(\delta_1 - \delta_0)^2} + (0.25)z_{1-\alpha}^2$$

where z_p is the p^{th} percentile of the standard normal distribution (Table A-1 of Appendix A). If $1.16m^* \leq m$ and $1.16n^* \leq n$, the false acceptance error rate has been satisfied.

STEP 6: The results of the test could be:

1) the null hypothesis was rejected, and it seems that population 1 is shifted to the right (Case 1), to the left (Case 2) or to the left or right (Case 3) of population 2.

2) the null hypothesis was not rejected, the false acceptance error rate was satisfied, and it seems that population 1 is shifted to the left (Case 1) or to the right (Case 2) of population 2, or there is no difference between the two populations (Case 3).

3) the null hypothesis was not rejected, the false acceptance error rate was not satisfied, and it seems that population 1 is shifted to the left (Case 1) or to the right (Case 2) of population

3.3.3.2 The Quantile Test

PURPOSE

The Quantile test can be used to compare two populations based on the independent random samples $X_1, X_2, \ldots, X_m$ from the first population and $Y_1, Y_2, \ldots, Y_n$ from the second population. When the Quantile test and the Wilcoxon rank sum test (Section 3.3.3.1) are applied together, the combined tests are the most powerful at detecting true differences between two populations. The Quantile test is useful in detecting instances where only parts of the data are different rather than a complete shift in the data. It essentially looks at a certain number of the largest data values to determine if too many data values from one population are present to be accounted for by pure chance.

ASSUMPTIONS AND THEIR VERIFICATION

The Quantile test assumes that the data $X_1, X_2, \ldots, X_m$ are a random sample from population 1, and the data $Y_1, Y_2, \ldots, Y_n$ are a random sample from population 2, and the two random samples are independent of one another. The validity of the random sampling and independence assumptions is assured by using proper randomization procedures, either random number generators or tables of random numbers. The primary verification required is to review the procedures used to select the sampling points. The two underlying distributions are assumed to have the same underlying dispersion (variance).

LIMITATIONS AND ROBUSTNESS

The Quantile test is not robust to outliers. In addition, the test assumes either a systematic (e.g., a triangular grid) or simple random sampling was employed. The Quantile test may not be used for stratified designs. In addition, exact false rejection error rates are not available, only approximate rates.

SEQUENCE OF STEPS

The Quantile test is difficult to implement by hand. Therefore, directions are not included in this guidance but the DataQUEST software (EPA, 1996) can be used to conduct this test. However, directions for a modified Quantile test that can be implemented by hand are contained in Box 3-23 and an example is given in Box 3-24.

Box 3-23: Directions for a Modified Quantile Test for Simple and Systematic Random Samples

Let there be 'm' measurements from population 1 (the reference area or group) and 'n' measurement from population 2 (the test area or group). The Modified Quantile test can be used to detect differences in shape and location of the two distributions. For this test, the significance level (α) can either be approximately 0.10 or approximately 0.05. The null hypothesis for this test is that the two population are the same (i.e., the test group is the same as the reference group) and the alternative is that population 2 has larger measurements than population 1 (i.e., the test group has larger values than the reference group).

STEP 1:	Combine the two samples and order them from smallest to largest keeping track of which sample a value came from.
STEP 2:	Using Table A-13 of Appendix A, determine the critical number (C) for a sample size n from the reference area, sample size m from the test area using the significance level α. If the C^{th} largest measurement of the combined population is the same as others, increase C to include all of these tied values.
STEP 3:	If the largest C measurements from the combined samples are all from population 2 (the test group), then reject the null hypothesis and conclude that there are differences between the two populations. Otherwise, the null hypothesis is not rejected and it appears that there is no difference between the two populations.

3.3.4 Comparing Two Medians

Let $\tilde{\mu}_1$ represent the median of population 1 and $\tilde{\mu}_2$ represent the median of population 2. The hypothesis considered in this section are:

Case 1: H_0: $\tilde{\mu}_1 - \tilde{\mu}_2 \leq \delta_0$ vs. H_A: $\tilde{\mu}_1 - \tilde{\mu}_2 > \delta_0$; and

Case 2: H_0: $\tilde{\mu}_1 - \tilde{\mu}_2 \geq \delta_0$ vs. H_A: $\tilde{\mu}_1 - \tilde{\mu}_2 < \delta_0$.

An example of a two-sample test for the difference between two population medians is comparing the median contaminant level at a Superfund site to the median of a background site. In this case, δ_0 would be zero.

The median is also the 50^{th} percentile, and, therefore, the methods described in Section 3.3.2 for percentiles and proportions may be used to test hypotheses concerning the difference between two medians by letting $P_1 = P_0 = 0.50$. The Wilcoxon rank sum test (Section 3.3.3.1) is also recommended for comparing two medians. This test is more powerful than those for proportions for symmetric distributions.

to departures from normality. With long-tailed distributions, the test too often rejects equality (homogeneity) of the variances.

Bartlett's test requires the calculation of the variance for each sample, then calculation of a statistic associated with the logarithm of these variances. This statistic is compared to tables and if it exceeds the tabulated value, the conclusion is that the variances differ as a complete set. It does *not* mean that one is significantly different from the others, nor that one or more are larger (smaller) than the rest. It simply implies the variances are unequal as a group. Directions for Bartlett's test are given in Box 4-24 and an example is given in Box 4-25.

4.5.4 Levene's Test for the Equality of Two or More Variances

Levene's test provides an alternative to Bartlett's test for homogeneity of variance (testing for differences among the dispersions of several groups). Levene's test is less sensitive to departures from normality than Bartlett's test and has greater power than Bartlett's for non-normal data. In addition, Levene's test has power nearly as great as Bartlett's test for normally distributed data. However, Levene's test is more difficult to apply than Bartlett's test since it involves applying an analysis of variance (ANOVA) to the absolute deviations from the group means. Directions and an example of Levene's test are contained in Box 4-26 and Box 4-27, respectively.

Box 4-24: Directions for Bartlett's Test

Consider k groups with a sample size of n_i for each group. Let N represent the total number of samples, i.e., let $N = n_1 + n_2 + \ldots + n_k$. For example, consider two wells where 4 samples have been taken from well 1 and 3 samples have been taken from well 2. In this case, k = 2, $n_1 = 4$, $n_2 = 3$, and N = 4 + 3 = 7.

STEP 1: For each of the k groups, calculate the sample variances, s_i^2 (Section 2.2.3).

STEP 2: Compute the pooled variance across groups: $$s_p^2 = \frac{1}{(N-k)} \sum_{i=1}^{k} (n_i - 1) s_i^2$$

STEP 3: Compute the test statistic: $$TS = (N - k) \ln(s_p^2) - \sum_{i=1}^{k} (n_i - 1) \ln(s_i^2)$$

where "ln" stands for natural logarithms.

STEP 4: Using a chi-squared table (Table A-8 of Appendix A), find the critical value for χ^2 with (k-1) degrees of freedom at a predetermined significance level. For example, for a significance level of 5% and 5 degrees of freedom, $\chi^2 = 11.1$. If the calculated value (*TS*) is greater than the tabulated value, conclude that the variances are not equal at that significance level.

Box 4-26: Directions for Levene's Test

Consider k groups with a sample size of n_i for the ith group. Let N represent the total number of samples, i.e., let $N = n_1 + n_2 + \ldots + n_k$. For example, consider two wells where 4 samples have been taken from well 1 and 3 samples have been taken from well 2. In this case, k = 2, $n_1 = 4$, $n_2 = 3$, and N = 4 + 3 = 7.

STEP 1: For each of the k groups, calculate the group mean, $\bar{x}_i$ (Section 2.2.2), i.e., calculate:

$$\bar{X}_1 = \frac{1}{n_1}\sum_{j=1}^{n_1} x_{1j}, \quad \bar{X}_2 = \frac{1}{n_2}\sum_{j=1}^{n_2} x_{2j}, \quad \ldots, \quad \bar{X}_k = \frac{1}{n_k}\sum_{j=1}^{n_k} x_{kj}.$$

STEP 2: Compute the absolute residuals $z_{ij} = |X_{ij} - \bar{X}_i|$ where X_{ij} represents the j^{th} value of the i^{th} group. For each of the k groups, calculate the means, $\bar{z}_i$, of these residuals, i.e., calculate:

$$\bar{z}_1 = \frac{1}{n_1}\sum_{j=1}^{n_1} z_{1j}, \quad \bar{z}_2 = \frac{1}{n_2}\sum_{j=1}^{n_2} z_{2j}, \quad \ldots, \quad \bar{z}_k = \frac{1}{n_k}\sum_{j=1}^{n_k} z_{kj}.$$

Also calculate the overall mean residual as $\bar{z} = \frac{1}{N}\sum_{i=1}^{k}\sum_{j=1}^{n_i} z_{ij} = \frac{1}{N}\sum_{i=1}^{k} n_i \bar{z}_i$.

STEP 3: Compute the following sums of squares for the absolute residuals:

$$SS_{TOTAL} = \sum_{i=1}^{k}\sum_{j=1}^{n_i} z_{ij}^2 - \frac{\bar{z}}{N}, \quad SS_{GROUPS} = \sum_{i=1}^{k}\frac{\bar{z}_i^2}{n_i} - \frac{\bar{z}}{N}, \text{ and } SS_{ERROR} = SS_{TOTAL} - SS_{GROUPS}.$$

STEP 4: Compute $f = \dfrac{SS_{GROUPS}/(k-1)}{SS_{ERROR}/(N-k)}$

STEP 5: Using Table A-9 of Appendix A, find the critical value of the F-distribution with (k-1) numerator degrees of freedom, (N-k) denominator degrees of freedom, and a desired level of significance (α). For example, if $\alpha = 0.05$, the numerator degrees of freedom is 5, and the denominator degrees of freedom is 18, then using Table A-9, F = 2.77. If f is greater than F, reject the assumptions of equal variances.

Box 4-27: An Example of Levene's Test

Four months of data on arsenic concentration were collected from six wells at a Superfund site. This data set is shown in the table below. Before analyzing this data, it is important to determine if the variances of the six wells are equal. Levene's test will be used to make this determination.

STEP 1: The group mean for each well ($\bar{x}_i$) is shown in the last row of the table below.

Arsenic Concentration (ppm)						
Month	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6
1	22.90	2.00	2.0	7.84	24.90	0.34
2	3.09	1.25	109.4	9.30	1.30	4.78
3	35.70	7.80	4.5	25.90	0.75	2.85
4	4.18	52.00	2.5	2.00	27.00	1.20
Group Means	$\bar{x}_1$=16.47	$\bar{x}_2$=15.76	$\bar{x}_3$=29.6	$\bar{x}_4$=11.26	$\bar{x}_5$=13.49	$\bar{x}_6$=2.29

STEP 2: To compute the absolute residuals z_{ij} in each well, the value 16.47 will be subtracted from Well 1 data, 15.76 from Well 2 data, 29.6 from Well 3 data, 11.26 from Well 4 data, 13.49 from Well 5 data, and 2.29 from Well 6 data. The resulting values are shown in the following table with the new well means ($\bar{z}_i$) and the total mean $\bar{z}$.

Residual Arsenic Concentration (ppm)						
Month	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6
1	6.43	13.76	27.6	3.42	11.41	1.95
2	13.38	14.51	79.8	1.96	12.19	2.49
3	19.23	7.96	25.1	14.64	12.74	0.56
4	12.29	36.24	27.1	9.26	13.51	1.09
Residual Means	$\bar{z}_1$=12.83	$\bar{z}_2$=18.12	$\bar{z}_3$=39.9	$\bar{z}_4$=7.32	$\bar{z}_5$=12.46	$\bar{z}_6$=1.52
Total Residual Mean $\bar{z}$ = (1/6)(12.83 + 18.12 + 39.9 + 7.32 + 12.46 + 1.52) = 15.36						

STEP 3: The sum of squares are: SS_{TOTAL} = 6300.89, SS_{WELLS} = 3522.90, and SS_{ERROR} = 2777.99.

STEP 4: $$f = \frac{SS_{WELLS}/(k-1)}{SS_{ERROR}/(N-k)} = \frac{3522.9/(6-1)}{2777.99/(24-6)} = 4.56$$

STEP 5: Using Table A-9 of Appendix A, the F statistic for 5 and 18 degrees of freedom with α = 0.05 is 2.77. Since f=4.56 exceeds $F_{.05}$=2.77, the assumption of equal variances should be rejected.

MICHIGAN DEPARTMENT OF NATURAL RESOURCES

INTEROFFICE COMMUNICATION

September 30, 1993

TO: Environmental Response Division Staff

FROM: Alan J. Howard, Chief, Environmental Response Division

SUBJECT: MERA Operational Memorandum #15: Default Type A Cleanup Criteria

In order to facilitate cleanup decisions at sites at which naturally occurring metals may be of concern, the following acceptable default Type A soil cleanup criteria have been established. These values are based on analysis of the database for the Michigan Background Soil Survey (April 1991) which is maintained by Waste Management Division (WMD). They represent the mean plus one standard deviation for WMD data from combined clay, topsoil, and sand categories. The values are presented in two significant figures. Data should be rounded to two significant figures for comparison.

Table 1: ACCEPTABLE DEFAULT VALUES TYPE A SOIL CLEANUP CRITERIA

Substance	Acceptable Concentration(mg/Kg)	Substance	Acceptable Concentration(mg/Kg)
Aluminum	6900	Iron	12000
Arsenic	5.8	Mercury	0.13
Barium	75	Lithium	9.8
Cadmium	1.2	Manganese	440
Cobalt	6.8	Nickel	20
Chromium	18	Lead	21
(total)	32	Selenium	0.41
Copper	0.39	Silver	1.0
Cyanide		Zinc	47

The default values apply as follows:

1. If measured concentrations at a site do not exceed the values listed in Table 1, site specific samples to establish background are not required.

2. The values apply to all soil types, statewide.

3. It is acceptable to establish site-specific background concentration higher than the default values. Such sampling should be conducted according to requirements in existence before the issuance of this memorandum. Comparison of site values is made against the mean plus three standard deviations calculated from background samples as

provided for in existing ERD guidance regarding verification of soil remediation.

4. Staff also may approve Type A cleanups based on a regionally proximate background value higher than the default values. Comparison should be made as in #3, above.

This memorandum is intended to provide guidance to Division staff to foster consistent application of the Michigan Environmental Response Act (1982 PA 307, as amended) and the Administrative Rules promulgated thereunder. This document is not intended to convey any rights to any parties or create any duties or responsibilities under law. This document and matters addressed herein are subject to revision.

Any questions about this memorandum should be directed to Bill Iversen at 517-373-0907.

rev. 0
cc: Dennis Drake, Air Quality Division
Bob Miller, Surface Water Quality Division
Tom Segall, Geological Survey Division
Jim Sygo, Waste Management Division

Appendix F – Sample Chain of Custody Form

TRACE
the science of compliance

phone 231.773.5998
toll-free 800.733.5998
fax 231.773.6537

Trace Analytical Laboratories, Inc.
2241 Black Creek Road
Muskegon, MI 49444-2673
www.trace-labs.com

CHAIN-OF-CUSTODY RECORD

Page_____of_____

TRACE ID NO.

TRACE USE ONLY

Logged By: Checked By:

Received on ice: Yes No Preservative Checked: Yes No N/A

Soil Volatiles Preserved: MeOH Low Level Lab Sampling Time:

Regulatory Requirements		Turnaround Requirements		Matrix Key	
MERA TMDL's	☐	Standard	☐	S = Soil/Solid	WI = Wipes
Drinking Water	☐	3 Day* ☐	4 Day* ☐	W = Water	LW = Liquid Waste
NPDES	☐	48 Hour* ☐	24 Hour* ☐	SL = Sludge	A = Air
Special	☐	** Requires Prior Approval*		OI = Oil	D = Drinking Water

Report Results To:

Company Name:

Report to:

Mailing Address:

City, State, Zip Code:

Phone: Fax:

Email Address:

Cell #: Sampled by:

Project Name & #:

Bill To:

Billing Address (if different) _____

City, State, Zip Code _____

Attn:_____ Phone: _____ PO #: _____

Request for Analytical Services

ANALYSIS REQUESTED

TRACE NO.	DATE TAKEN	TIME TAKEN	CLIENT SAMPLE ID	METALS FIELD FILTERED	MATRIX	NUMBER OF CONTAINERS	PRESERVATION: COOL	HCL	HNO_3	H_2SO_4	NaOH	Other	REMARKS	Possible Health Hazards

Please Sign

RELEASED BY	RECEIVED BY	DATE	TIME	RELEASED BY	RECEIVED BY	DATE	TIME	RELEASED BY	RECEIVED BY	DATE	TIME
1)				2)				3)			
4)				5)				6)			

In executing this Chain of Custody, the client acknowledges acceptance of the terms and conditions of the agreement as set forth at http://www.trace-labs.com/cocterms.php