National Park Service
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Natural Resource Program Center

Water Quality Monitoring Protocol for Inland Lakes
Great Lakes Inventory and Monitoring Network

Natural Resource Report NPS/GLKN/NRTR—2008/109



ON THE COVER
Portaging between Lake Superior and an inland lake at Isle Royale National Park.
Photograph by: Valena Hofman.

Water Quality Monitoring Protocol for Inland Lakes
Great Lakes Inventory and Monitoring Network

Version 1.0

Natural Resource Technical Report NPS/GLKN/NRTR—2008/109

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Note:

The Inland Lakes Water Quality Monitoring Protocol consists of the following:

1. Protocol Narrative
2. Standard Operating Procedures

SOP #1: Pre-season Preparation
SOP #2: Training and Safety
SOP #3: Using the GPS
SOP #4: Measuring Water Level
SOP #5: Decontamination of Equipment to Remove Exotic Species
SOP #6: Field Measurements and Water Sample Collection
SOP #7: Processing Water Samples and Analytical Laboratory Requirements
SOP #8: Data Entry and Management
SOP #9: Data Analysis
SOP #10: Reporting
SOP #11: Post- Season Procedures
SOP #12: Quality Assurance/Quality Control
SOP #13: Procedure for Revising the Protocol

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Revision History Log

The following table lists all edits and amendments to this document since the original publication date. Information entered in the log must be complete and concise. Users of this standard operating procedure will promptly notify the project manager and/or the Great Lakes Network (GLKN) data manager about recommended and required changes. The project manager must review and incorporate all changes, complete the revision history log, and change the date and version number on the title page and in the header of the document file. For complete instructions, please refer to Revising the Protocol, SOP #13.

Revision History Log:

Previous Version #	Revision Date	Author (with title and affiliation)	Location in Document and Concise Description of Revision	Reason for Change	New Version #
Add rows as needed for each change or set of changes tied to an updated version number					

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We relied heavily on the monitoring protocols of others, especially those of the Greater Yellowstone Network (O'Ney 2005a) and San Francisco Area Network (Cooprider 2005)

Finally, we would like to acknowledge the many reviewers who provided valuable comments on an earlier version of this protocol.

1.0 Background and Objectives

Inland lakes are important and valuable resources at six of the parks of the Great Lakes Network (Apostle Islands National Lakeshore (APIS), Indiana Dunes National Lakeshore (INDU), Isle Royale National Park (ISRO), Pictured Rocks National Lakeshore (PIRO), Sleeping Bear Dunes National Lakeshore (SLBE), and Voyageurs National Park (VOYA)). The Great Lakes Network (hereafter, GLKN or the Network) parks encompass a variety of aquatic habitats and biota, including 129 named lakes, totaling nearly 41,000 ha (101,000 acres) (Lafrancois and Glase 2005).

This protocol addresses monitoring of inland lakes to assess change in basic limnological parameters, including those mandated by the National Park Service (detailed below), for the purpose of tracking changes in water quality over time.

1.1 Rationale for Selecting this Resource to Monitor

Water quality is generally high throughout GLKN parks, though threats exist from atmospheric deposition, urban and agricultural runoff, wastewater discharges and seepage from septic systems, recreational use, and other anthropogenic impacts. Network lakes listed as impaired under Section 303(d) of the Clean Water Act are only so designated because of fish consumption advisories (Ledder 2003). All lakes in the State of Michigan have fish consumption advisories (FCAs) for mercury (MDCH 2004), as do most lakes in VOYA (MPCA 2006, NPS 2005) and Lake George, at INDU (NPS 2005). In addition, Siskiwit Lake, at ISRO, has a FCA for polychlorinated biphenyls (PCBs) and Big Glen Lake, at SLBE, has a FCA for PCBs and chlordane. When lagoons are connected to Lake Superior, they are under FCAs for PCBs (NPS 2005), however these lagoons are sometimes isolated from the lake. All waterbodies within INDU, ISRO, PIRO, and SLBE are designated Outstanding State Resource Waters, and all those in VOYA are designated Outstanding Resource Waters. Lake Superior waters within APIS boundaries are designated Outstanding Natural Resource Waters by the state, and Lake Superior as a whole is designated as federal Outstanding Resource Waters (Ledder 2003).

Although the water quality of most inland lakes is currently relatively good at GLKN parks, conditions can change quickly. It is important to detect change as early as possible, in order to maximize the potential for effective management actions. Park lakes are used extensively by visitors for fishing, boating, swimming, and other recreational activities. The four large lakes at VOYA are impounded for generating hydropower; the levels are controlled through an international agreement (The International Joint Commission). Because the preservation of lake water quality and quantity is of utmost importance to park managers, researchers, and the general public, monitoring basic water quality ranked among the highest of the Network's vital signs (Route 2004).

1.2 Key Variables of Interest

A national review panel assembled by the National Park Service – Water Resources Division (NPS-WRD) recommended a suite of five parameters be measured across all NPS monitoring networks (NPS 2002). In addition to these five mandated parameters (temperature, pH, specific conductance, dissolved oxygen, and flow/water level) we added a measure of water clarity (Secchi depth or transparency tube depth) to our core suite. The core suite was ranked highest among potential vital signs for aquatic systems of GLKN parks, although it was recognized that these measurements were less diagnostic of water quality degradation than biotic communities and other water quality variables, such as nutrient concentrations.

Inputs of excess nutrients, invasion and spread of exotic species, and contaminants from atmospheric fallout and surface runoff, and how these stressors affect the chemical and biological functions of lakes are key issues of concern. By monitoring an advanced suite of parameters (nitrogen and phosphorus species, dissolved organic carbon, major ions, dissolved silica, and chlorophyll-*a*), we will provide data for a more thorough understanding of changes in lakes over time.

1.2.1 Temperature

Water temperature exerts a major influence on the activity, growth, distribution, and survival of aquatic biota. Fish, insects, zooplankton, phytoplankton, and other aquatic organisms all have preferred temperature ranges for optimal health and reproduction. Temperature is also important because of its influence on water chemistry and physical processes, such as evaporation, oxygen (and other gas) diffusion rates, chemical reaction rates, particle settling velocities (via viscosity), and the stability of thermal stratification. Temperature, via its effect on water density, also acts to structure deeper lakes into distinct layers with profound physical and chemical differences that create a diversity of habitats for organisms (e.g., Wetzel 2001).

1.2.2 Specific Electrical Conductivity (EC25 or SC25)

Electrical conductivity is a measure of the capacity of water to conduct an electrical current. Specific conductivity (called EC25 or SC25) is the 'raw' conductivity normalized to unit length and cross-section at 25 °C. This normalization eliminates its temperature dependent variability and makes it a good estimator and surrogate measure of the concentration of total dissolved ions in the water. The magnitude of SC25 is controlled largely by geology (rock types) in the watershed, which determines the chemistry of the watershed soil and ultimately the lake. The size of the watershed relative to the area of the lake (Aw:Ao ratio) also affects SC25, with a larger ratio indicating that relatively more water drains into the lake because of a larger catchment area and has more contact with soil before reaching the lake. Increased SC25 may indicate a number of sources of pollutants, such as wastewater from sewage treatment plants or on-site septic systems, urban runoff from roads (especially road salt), agricultural runoff, and atmospheric deposition. Increased conductivity from runoff into soft waters can be a major stressor to salmonids, shoreline and nearshore plants, and other aquatic organisms. Conductivity is an important indicator of polluted runoff that may contain excess nutrients, organic matter, pathogenic microbes, heavy metals, and organic contaminants. SC25 increases naturally due to evaporative salt concentration and respiration, which increases bicarbonate and carbonate

concentrations. It is also an excellent 'tracer' of water masses in the lake, as well as tributary and groundwater inflows.

1.2.3 pH

The pH value is the negative logarithm of the hydrogen ion (H^+) activity in the water. At higher pH levels, fewer free hydrogen ions are present; a change of one pH unit (e.g., pH 7 to pH 8) reflects a tenfold change in the concentrations of the hydrogen ion. A closely related parameter is the alkalinity or acid-neutralizing capacity (ANC,) which is a measure of the buffering capacity of the water. The pH of water determines the solubility and biological availability of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc.). pH is generally used to set water quality criteria for lakes and streams because of its potential impacts to the life cycle stages of aquatic macroinvertebrates and certain salmonids that can be adversely affected when pH levels are above 9.0 or below 6.5 (Stednick and Gilbert 1998). The mobility of many metals is also enhanced by low pH and can be important in assessing mining impacts. Estimating the toxicity of ammonia, aluminum, and some other contaminants requires accurate pH values. Daily and seasonal variability in pH is associated with natural changes in biological photosynthesis and respiration, as well as inputs from runoff and atmospheric deposition (e.g., Schindler 1988, Schindler et al. 1985). When nutrient pollution results in higher algal and plant growth (e.g., from increased temperature or excess nutrients), pH levels may increase, as allowed by the buffering capacity of the lake. Although these small changes in pH are not likely to have a direct impact on aquatic life, they greatly influence the availability and solubility of all chemical forms in the lake and may aggravate nutrient problems.

1.2.4 Dissolved Oxygen (Concentration and % Saturation)

Dissolved oxygen (DO) is a measure of the amount of oxygen in solution. Oxygen solubility is controlled largely by water temperature and the partial pressure of oxygen within gasses in contact with the solution. Its concentration in any stratum of water is determined by the net difference between its sources and its sinks. Oxygen transfer from the atmosphere to the water and from one depth to another depends on its diffusion rate, which is highest in the upper, turbulent wind-mixed layer (epilimnion) and very low in the hypolimnion. The largest source of O_2 is the atmosphere, but phytoplankton and macrophyte photosynthesis produce O_2 during daylight hours and tributaries can contribute significant DO to specific layers of water. The major sink for DO is respiration by animals, plants, and microbes, occurring throughout the day. Because photosynthesis is light dependent, and surface mixing is largely dependent on wind energy and morphometry (in the sense of wave height and fetch), DO levels can vary throughout the day, season, and with depth. Temperature controls the potential O_2 saturation, although water can supersaturate from high turbulence (e.g., waterfalls) or photosynthesis from algal blooms in hypereutrophic lakes.

A DO level > 1 mg/L is generally accepted as a chronic minimum for most aquatic animals; 5 mg/L is a chronic minimum for the maintenance and survival of most aquatic organisms and is a common regulatory criterion for supporting a cold water fishery. As water becomes warmer it can hold less DO. If the water becomes too warm, even if 100% saturated, O_2 levels may be suboptimal for many species of trout. Mid-summer may be a critical time for some fish because

epilimnetic water is too warm for them, and while hypolimnetic water may be an optimal temperature, it may have too little oxygen.

1.2.5 Lake Level

Accurate lake level measurements are highly recommended as per NPS monitoring guidelines (NPS 2002) and are needed primarily because of their importance in defining the spatial extent of littoral zones. These shallow water areas provide critical habitat for many aquatic organisms and are nursery areas for both planktivorous and piscivorous fish at various stages of their life cycles. Accurate volumetric estimates, hydrologic budgets, heat budgets and mass balance budgets for chemical compounds and oxygen also require accurate lake levels. In reservoirs and lake level controlled systems such as Lake Kabetogema in VOYA, lake levels and discharge from the lake are controversial management issues (Kallemeyn et al. 2003). Fluctuations in lake level are also important in terms of nearshore development, wetland conservation and function (Mitsch and Gosselink 2000), and nutrient and mercury cycling (Christensen et al. 2004).

1.2.6 Water Clarity

Although not a mandated parameter, GLKN has included a measure of water clarity (Secchi depth and/or transparency tube depth) in the core suite of parameters because of its fundamental importance to whole-lake ecology, ease of measurement, and the fact that it will always be measured along with core suite profiles. Light penetration, for which water clarity is a surrogate, is an important regulator of rate of primary production and plant species composition, including the balance between phytoplankton and macrophyte production in shallow lakes (e.g., Moss et al. 1996). Water clarity provides a visual measurement that relates directly to the aesthetic perceptions of the general public. Secchi depth can also be an effective indicator of non-algal suspended sediment loading from agricultural and urban runoff and from shoreline erosion (Swift et al. 2006, Holdren et al. 2001, Preisendorfer 1986). Secchi depth transparency has a long history of use in lake monitoring programs as an excellent indicator of trends in phytoplankton biomass (e.g., WOW 2005, Goldman 1988), and is an integral component of Upper Great Lakes States Monitoring programs (e.g., WDNR 2005; MPCA 2005a, 2004c; MDEQ 2004, 2001).

1.2.7 Major Ions

- Cations - calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^{+}), and potassium (K^{+})
- Anions - $SO4^{-2}$, Chloride (Cl^{-}), and alkalinity ($CaCO_3$)

The chemical composition of a lake is a function of land use, climate, and basin geology. Each lake has an ion balance of the three major anions and four major cations (Table 1). The ionic concentrations influence the lake's ability to assimilate pollutants (e.g., acidification) and maintain nutrients in solution. For example, calcium carbonate ($CaCO_3$) in the form known as marl can precipitate phosphate from the water, thereby removing this important nutrient from the water. High Ca^{+2} and Mg^{+2} directly reduce the bioavailability and toxicity of many heavy metals, and indirectly affect mercury cycling (e.g., Horne and Goldman 1994, Driscoll et al. 1994, 1995).

Table 1. Ion balance typical for fresh water in the Upper Midwest (Wetzel 2001, Horne and Goldman 1994).

Anions	Percent	Cations	Percent
HCO_3^-	73%	Ca^{+2}	63%
SO_4^{-2}	16%	Mg^{+2}	17%
Cl^-	10%	Na^+	15%
		K^+	4%
other	< 1%	other	< 1%

Bicarbonate and carbonate ions, which are estimated by alkalinity, dominate the major anions. Alkalinity directly estimates the majority of the buffering capacity of the water and is used to estimate sensitivity to acid precipitation. Sulfate concentrations provide a measure of the potential accumulation of sulfur due to acidic deposition of SO_x compounds and are important for assessing acid deposition effects. Sulfate is also a critical parameter for understanding and modeling mercury cycling because sulfate-reducing bacteria in anoxic environments are the primary source of methyl mercury, the major fraction involved in the bioaccumulation of mercury in food webs (e.g., Driscoll et al. 1994). Chloride (Cl^-) is a particularly good indicator of wastewater plumes as well as inputs and accumulation of road salt. It may be used as a tracer, as it moves through soil without significant absorption or adsorption.

The concentration of the major ions and their relative ratios influence the species of organisms that can best survive in a lake, in addition to affecting many important chemical reactions that occur in the water. Zebra mussels (*Dreissena polymorpha*), for example, require levels of calcium typically higher than those found in Lake Superior water, though this exotic species has invaded several inland lakes at SLBE. Humans can have profound influences on the characteristics of lake chemistry, including ion concentrations. Modification of natural shoreline vegetation and increasing the amount of impervious surfaces surrounding a lake cause increased runoff, which can carry chloride and potassium from the use of road salt.

1.2.8 Dissolved Silica (SiO_2)

Silica is considered an essential micronutrient for microorganisms and diatom algae. These organisms use silica to form shells and other protective structures. Diatoms are capable of using large amounts of silica, and may be growth-limited when silica is in short supply.

1.2.9 Dissolved Organic Carbon (DOC)

Dissolved organic carbon (DOC) is usually the largest fraction of organic material in the open waters of lakes. (Exceptions generally involve hypereutrophic lakes with intense blooms of algae or an abundance of aquatic plants that die off in the fall.) It is derived primarily from decomposing material in the watershed that is leached into stream and groundwater inputs and washed in from wetlands with abundant sphagnum mosses (Wetzel 2001, Schindler and Curtis 1997). Typically, a lesser amount is contributed by algae, both from extracellular leakage and via decomposition; concentrations may be high following intense algae blooms. DOC plays important roles in freshwater ecosystems , including 1) affecting acid-base chemistry and metal

cycling (e.g., copper, mercury, aluminum), and potential toxicity; 2) acting as a source of energy and nutrients to the microbial food chain, thereby influencing nutrient availability; 3) attenuating UV-B radiation; 4) attenuating PAR (photosynthetically active radiation) and thereby regulating primary production; and 5) influencing the heat budget of the lake by absorbing sunlight (Gergel et al. 1999, Schindler and Curtis 1997). Anthropogenic stressors, such as global warming, ozone losses, acidification, and intensive logging are cause for concern as they may be altering the concentration and distribution of DOC, resulting in adverse effects on lakes.

1.2.10 Nutrients (Total Phosphorus [TP], Total Nitrogen [TN], Nitrate+Nitrite-N [NO_3+NO_2-N], and Ammonium-N [NH_4-N])

Nitrogen and phosphorus are the two most influential nutrients in terms of regulating phytoplankton and aquatic macrophyte growth. Excessive inputs of nutrients can lead to excessive algal growth and eutrophication (Wetzel 2001, Horne and Goldman 1994) and are the most important threat to Upper Midwest lakes (MPCA 2004a, c; MDEQ 2004; WDNR 2005).

Nutrients are carried into a waterbody primarily through surface runoff and percolation through the surrounding rocks and soils. Bioavailable forms of phosphorus and nitrogen (dissolved phosphate, nitrate, and ammonium) are typically highest in the spring due to snowmelt runoff and the mixing of accumulated nutrients from the bottom during spring turnover. Concentrations typically decrease in the epilimnion during summer stratification, as nutrients are taken up by algae and eventually transported to the hypolimnion when the algae die and settle out. When stratified, any input of nutrients into the upper lake water may trigger a bloom of algae. In less productive systems, such as many of those in GLKN parks, significant amounts of available nitrogen may be deposited during rainfall or snowfall events (wet deposition) and through the less obvious deposition of aerosols and dust particles (dry deposition). Nitrogen and phosphorus in dry fallout and wet precipitation may come from dust, fine soil particles, and fertilizer from agricultural fields.

1.2.11 Chlorophyll-a

The concentration of chlorophyll-*a*, the primary photosynthetic pigment in all green plants including phytoplankton, is a nearly universally accepted measure of algal biomass in the open waters of lakes (e.g., Wetzel 2001, Wetzel and Likens 2000). However, it may also be important to examine the algal community microscopically on occasion, because the mix of species can influence chlorophyll-*a* concentration, as different algal groups have different proportions of chlorophyll-*a* versus other pigments. Hence, chlorophyll-*a* is not always an accurate measure of biomass, and the mix of species may influence lake management decisions. Chlorophyll-*a* concentrations are expected to be dynamic, reflecting changes in algal abundance through the ice-free growing season. Consistent and directional trends in chlorophyll-*a* concentrations are good indicators of change in a lake's trophic status Wetzel 2001, Carlson and Simpson 1996, Horne and Goldman 1994).

1.3 Background and History; Description of Resource

Several efforts have been undertaken in recent years to organize and synthesize aquatic resource data from GLKN parks. Most recently, Lafrancois and Glase (2005) published a summary and

synthesis of information from over 600 studies. This synthesis will help guide management, future research, and monitoring efforts. The authors noted that much of the existing research in Great Lakes area parks was from short-term projects conducted by many different people without common methods or objectives, and that a comprehensive, network-wide analysis of the available information for use in identifying and addressing large-scale water resource issues had not been done previously.

Ledder (2003, 2005) summarized relevant numeric water quality standards in addition to compiling lists of designated uses for parameters of interest to the water quality monitoring project. Her summaries included relevant water quality criteria, waterbodies that are listed under section 303(d) of the Clean Water Act, and waterbodies with Outstanding Resource Waters designation.

Historical water quality data for inland lakes of the parks consist of lake profile data (temperature, dissolved oxygen, specific conductivity, pH, and Secchi depth) as well as various other physical, chemical, and biological (chlorophyll-*a*) parameters (Table 2). See Lafrancois and Glase (2005) for a more complete listing of aquatic research and monitoring efforts in GLKN park units. The Natural Resources Research Institute (NRRI) at the University of Minnesota – Duluth (UMD) analyzed water quality data collected between 1997 and 2003 from lakes at SLBE, PIRO, and APIS (Axler et al. 2006). Other in-depth analyses of water quality data at ISRO and VOYA have been published recently (Kallemeyn et al. 2003, Kallemeyn 2000).

The National Park Service-Water Resources Division (NPS-WRD) retrieved data from several EPA databases, including STOrage and RETrieval System (STORET), and summarized these data for national park units (1999 [APIS], 1997 [SLBE], 1995a [ISRO], 1995b [PIRO], 1995c [VOYA], NPS 1994 [INDU]). Summaries include exceedance data, by station.

1.3.1 Water Quality Monitoring Efforts by Parks

Water quality monitoring programs conducted by the parks vary widely, and in most parks, have changed over time. Park funding and turnover of personnel have fluctuated, and the parks are not always able to continue monitoring programs on schedule. A brief synopsis of park water quality monitoring programs follows.

Until 1988, water quality studies at APIS were largely synoptic rather than routine monitoring efforts. At that time, Michigan Technical University established a monitoring program that the park has attempted to continue, conducting routine monitoring with a multi-parameter sonde every two to three years at five sites in Lake Superior and in three lagoons. More intensive physical, chemical, and biological monitoring was conducted by different research groups at the same sites in 1996 and 2004.

Table 2. Summary of water quality data available for inland lakes at Great Lakes Network parks.

Park	Source	Period of Record	Water Quality Parameters (Lakes)
VOYA	Kallemeyn 2003	2003	chlorophyll and TP (Rainy, Sand Pt, Namakan, Kabetogama)
	NRRI CAL	2002	chlorophyll and TP (Rainy, Sand Pt, Namakan, Kabetogama)
	Hargis 1981	1978-80	core suite, chlorophyll, % light transmittance (Rainy, Sand Pt., Namakan, Kabetogama, Ek 1978-80, 19 interior lakes1979-80)
	Payne 1991	1977-2000	USGS & NPS; Rainy, Sand Pt., Namakan, Kabetogama, 19 interior, 2 streams. chlorophyll, Secchi, TN, TP, alkalinity, cations, anions
	Payne 2000	1999	Rainy, Sand Pt., Namakan, Kabetogama
	VOYA/USGS	1981/83	1981 Namakan and Kabetogama, 1983 Rainy and Sand Pt. 11xs/summer, 26 interior lakes at least once
	Kepner 1988	NA	Rainy, Sand Pt., Namakan, Kabetogama
	MPCA	2000	12 lakes
	Eibler 2001	1983-2000	MNDNR; 1x/summer; Kabetogama, Rainy, maybe Namakan and Sand Pt.; chlorophyll, Secchi, alkalinity
	Newell 1987 Webster 1995	1978-1995	USEPA-LTM; (Cruiser, Loiten, Locator, Shoepack)
	Whitman 2001	1997-98	Locator and Mukooda: chlorophyll, pH, ANC, SO4
INDU	NPS	1990-2000	alkalinity, NH4, Cl, SC25, dissolved oxygen, NO3, NO2, pH, TP, hardness, turbidity
	Arihood 1975	1973-1974	chemical, organic, bacteriological; ground and surface waters
	Hardy 1983	1978-1980	core suite, periphyton, bacteriological
	Whitman et al. 1995	1991	core suite, bacteriological
	Simon et al. 1997		pH, conductivity. major ions, nutrients, morphometry; 4 lakes
ISRO	NRRI CAL	1996 1997	Secchi, core suite, chlorophyll, nutrients, major ions SC25, DOC, color- 32 lakes
	Stottlemeyer 2000	1980-96	
	Kallemeyn 2000	1995-97	summarized data, core and advanced
	Gorski 2002	1998-99	DOC and Hg
PIRO	Handy & Twenter 1985	1979-81	once/year (Chapel, Beaver, Kingston, Grand Sable), temp, SC25, pH, and advanced suite
	Loope 1998		review of six inland lakes
	Kamke 1987		4 lakes (Chapel, Beaver, Kingston, Grand Sable)
	PIRO 1998	1970-2002, intermittant	lake profiles (core parameters) and field notes only 1998 and 1999 multiple/year, the rest once/year
APIS	Balcer & McCauley (1989)	1986-89	fecal bacteria, nutrients, sediment composition, core suite (Lake Superior, lagoons)
	Rose 1988	1983	USGS - Outer Island Lagoon; 2x/summer; core suite, anion, cations, nutrients
	Rose 1988	1984	USGS - Michigan Island Lagoon; 2x/summer; core suite, anion, cations, nutrients
	MTU 1997	1996	Michigan, Outer, Stockton Islands Lagoons; core suite, chlorophyll, nutrients, zooplankton, benthos; June, July, Aug.
	Axler et al. 2006	2005	Michigan, Outer, Stockton Islands Lagoons; core suite, chlorophyll, nutrients, zooplankton, benthos; June, Aug., Oct.
SLBE	SLBE	1997-2003	Secchi, profiles, water chemistry
	Murphy 2001, 2002	2000 - 2002	core suite, turbidity, nutrients, major ions; inland lakes and rivers
	Last et al. 1995	1994-1995	core suite, chlorophyll-*a*

Notes: NRRI-CAL = Natural Resources Research Institute Central Analytical Laboratory; MPCA = Minnesota Pollution Control Agency.

Intensive and extensive water quality studies have been conducted at INDU over the years (Lafrancois and Glase 2005). Researchers often focused on contaminants from industrial waste, although basic water quality parameters were also measured. From 1990 through 2000, the park monitored alkalinity, ammonium, chloride, specific conductance, dissolved oxygen, nitrate, nitrite, pH, total phosphorus, hardness, and turbidity of Long Lake. The park conducts routine bacteriological monitoring at Lake Michigan beach sites.

Two long-term water quality monitoring projects have occurred at ISRO - one at the Washington Creek gaging station, and the other a study of the Wallace Lake watershed. A number of additional inland lakes have been studied intensively for short periods of time, although no long-term water quality monitoring has been conducted on ISRO's inland lakes.

Most of the inland lakes at PIRO have been sampled at least once, with few lakes receiving greater attention in the form of synoptic studies. Beginning in 1994, annual data were collected, once in mid-summer, on six lakes with a multi-parameter sonde. For the first three years (1994-1996), nitrate, phosphate, and chlorophyll-*a* were also measured.

Prior to 2001, most water quality sampling at SLBE was conducted as part of synoptic studies to address particular concerns in a given lake or stream (e.g., nutrient loading downstream from a fish hatchery). Since 2001, however, park staff have conducted water quality monitoring routinely in most lakes of the park. Parameters typically measured were Secchi depth; profiles of temperature, dissolved oxygen, specific conductance, and pH; and less routinely, total dissolved solids, sulfate, calcium hardness, total hardness, total nitrogen, total phosphorus, nitrate, ammonium, alkalinity, true color, and chlorophyll-*a*. Bacteriological monitoring is also conducted weekly at beach sites from mid-May through mid-September.

The four large, regulated lakes at VOYA have been monitored for the past 25 years, every two weeks from May until October. Parameters measured in this program are temperature and dissolved oxygen profiles, alkalinity, pH, conductivity, and Secchi depth. Chlorophyll-*a* has also been measured on these lakes since 2000. Inland lakes of the park have not received the same continuous monitoring effort, though many intensive project-based studies have been conducted. Kallemeyn et al. (2003) analyzed and summarized historical water quality data of inland lakes.

1.3.2 Description of Parks' Inland Lakes

The inland lake resources of GLKN parks are astounding, numbering in the thousands. Lakes greater than one hectare number in the hundreds, with VOYA, alone, containing nearly 300 (Table 3).

Table 3. Number of lakes > 1 hectare in six Great Lakes Network parks. Number of inland lakes between 1 and 10 hectares in parentheses. Source of data is the National Hydrologic Database.

Park	Number of Inland Lakes > 1 Hectare (1 – 10 ha)
Apostle Islands National Lakeshore	11 (10)
Indiana Dunes National Lakeshore	8 (8)
Isle Royale National Park	77 (59)
Pictured Rocks National Lakeshore	24 (10)
Sleeping Bear Dunes National Lakeshore	24 (7)
Voyageurs National Park	299 (268)

The water chemistry of inland lakes varies widely across the Network. Lakes in SLBE are underlain by limestone, and hence have relatively high pH values (most lakes > 8.0), high buffering capacity (alkalinity of most lakes > 125 mg/L), and high conductivity values (many lakes SC25 > 300 µS/cm). Pictured Rocks National Lakeshore contains a meromictic lake (Chapel Lake), > 42 m deep, and a naturally acidic lake (Legion Lake), with pH values generally < 5.0 and alkalinity near zero (Loope 1998). Some lakes at VOYA are underlain by granitic bedrock of the Canadian Shield, while others are underlain by thick calcareous drift. The differences in water chemistry within this park are great; some lakes are poorly buffered, some are well-buffered, some have noxious blooms of blue-green algae, and some are oligotrophic (Kallemeyn et al. 2003).

Accessibility of lakes also varies across the Network, which affects the types of stressors influencing the lakes' water quality. Many park lakes require substantial time and effort to gain access. For example, Lake Manitou, at SLBE, requires a boat ride across Lake Michigan waters and then a portage of approximately 4 km (2.5 mi); Lake Desor, at ISRO, requires approximately an hour of boat transportation on Lake Superior followed by a steep off-trail bushwhack portage of approximately 1.6 km (1 mi). Lakes such as these receive little recreational pressure and no developmental effects. The primary stressors are likely due to atmospheric deposition and global climate change. The large lakes at VOYA receive house-boat use, and are therefore at risk from inputs of excess nutrients from gray water discharge and failing sewage holding tanks. Many lakes within the Network are located alongside of roads, accessed via boat ramps, and contain developed areas of shoreline. These lakes are affected by stressors such as road salt, runoff, oil and gas, failing septic tanks, invasive species, as well as the same atmospheric threats that face remote lakes.

With this monitoring protocol, we hope to encompass the variety of existing lake conditions and stressors affecting thee lakes. The sampling design and methods of field sampling are described in the following sections (2.0 Sample Design, and 3.0 Field Methods).

1.4 Measurable Objectives

Our overall goal is to develop a program for monitoring water quality in inland lakes that will contribute to an understanding of the health of aquatic ecosystems and provide insights on likely water resources issues in park units of the Great Lakes Network.

Our specific objective is to monitor basic limnological parameters that describe water quality of select inland lakes in order to describe the current status and trends (i.e., magnitude and direction of change) of these lakes. We will examine parallel trends across lakes within park units and across the Network as a whole, and compare our results with other regional datasets.

1.5 Quality Assurance and Quality Control

Quality control is the planned and systematic pattern of all actions, or controls, necessary to provide adequate confidence that a project outcome optimally fulfills expectations. Quality assurance is a program for the systematic monitoring and evaluation of the various aspects of a project to ensure that standards of quality are being met. Together, quality assurance/quality control (QA/QC) is a significant part of any monitoring program. It is a broad management concept of maintaining the ability to provide reliable information, requiring the complete integration of field and laboratory systems of sample collection and analysis. QA/QC incorporates peripheral but essential operations such as survey design, equipment preparation, maintenance tasks, data handling, and personnel training. The objective of QA/QC is to ensure that the data generated by a project are meaningful, representative, complete, precise, accurate, comparable, and scientifically defensible (O'Ney 2005a).

This protocol includes QA/QC procedures that must be followed, beginning with field preparations, through the collection of data, to the final analyses and reporting of results. See standard operating procedure (SOP) #12 for QA/QC details.

2.0 SAMPLE DESIGN

2.1 Rationale for Selecting this Sampling Design

As we developed our sampling design, we explored the advantages and disadvantages of randomly selecting lakes for monitoring versus a nonrandom selection of lakes. We also considered the sampling designs of Minnesota, Wisconsin, and Michigan - three of the four states in which Network parks are located. These three states have the greatest numbers of lakes of the lower 48 states, and all three have active water quality monitoring programs.

In the following paragraphs, we describe random, or probabilistic, and nonrandom, or targeted, selection of lakes for monitoring; we summarize the water quality monitoring programs of the three states; and we explain our design for long-term monitoring of water quality of inland lakes in the Great Lakes Network.

2.1.1 Random Versus Nonrandom Selection of Lakes

Historically, monitoring programs for lakes have focused on either representative lakes or on specific lakes of particular interest. Examples of lakes selected for particular reasons include:

- lakes with outstanding resource value - for example, the Lake Tahoe, California-Nevada program (Goldman 1988, Jassby et al. 2003), Lake Michigan (e.g,. Fahnenstiel and Scavia 1987, Madenjian et al. 2002), Crater Lake, Oregon (LaBounty and Larson 1996);

- lakes representative of a class of lake types, for example, meso-oligotrophic (e.g., Castle Lake, California; Jassby et al. 1999, Goldman et al. 1989), eutrophic (Clear Lake, California; Suchanek et al. 2002), acid-sensitive Canadian shield lakes (Schindler et al. 1985, Schindler 1988);

- lakes within a geographic area, for example, lakes and reservoirs of the southeastern U.S. (Reckhow 1988), lakes of the northeastern United States (Messer et al. 1991), long-term ecological research of North Temperate Lakes (Magnuson et al. 2006, Magnuson et al. 1984), recreational lakes in Vermont (Smeltzer et al. 1989);

- economically important lakes under heavy anthropogenic stress, for example, Lake Mendota, Wisconsin (Lathrop et al. 1996); Lake Washington, Washington (Edmonson 1996); Lake Okechobee, Florida (Steinman et al. 2001); Lake Minnetonka, Minnesota (Barten, 2004); Lake Mead, Nevada-Arizona (Paulson and Baker 1983, LaBounty and Horn 1997); Lake Tahoe, California-Nevada (Jassby et al. 1999).

Such nonrandom selection of lakes in a monitoring program allows results to be used in answering specific questions about a particular lake or suite of lakes. The main disadvantage of this design, however, is that inferences cannot be extended to lakes beyond those that are sampled.

Beginning with concerns about the potential degradation of softwater lakes throughout the U.S. due to acidic deposition, the U.S. Environmental Protection Agency (EPA) initiated the

development of a framework for probabilistic design and sampling. The approach has now moved beyond the acid-rain question to provide an approach that allows quantitative (i.e., with known statistical confidence) descriptions of aquatic resources.

A probabilistic, randomized sampling scheme is particularly well suited to examining large populations of lakes, to groups of lakes that have little prior information, and where one wishes to characterize populations or groups with a particular degree of statistical confidence. The advantage of a random design is that probabilistic statements can be made about differences in means. This ability to make statistical inferences to a large population of lakes from a relatively small number that are actually sampled makes the randomized method appear preferable because a comparison between groups of lakes or a trend over time can be justified with confidence limits. An important disadvantage of the randomized design is that in order to make useful probabilistic statements about responses in a larger population of lakes within a few years, the number of lakes in the sampling program must be relatively large (20 to 30% of the total population of lakes; e.g., Loeb 2002).

2.1.2 Current Lake-Monitoring Programs of States Within the Great Lakes Region

It is important that GLKN develops a program for monitoring water quality that is comparable with and acceptable to other regional monitoring programs, especially the states. Monitoring programs in Minnesota, Wisconsin, and Michigan have been in existence for many years, and all three have undergone changes in the past few years to enable the states to more efficiently comply with their assessment and reporting responsibilities for the federal Clean Water Act (see http://www.pca.state.mn.us/publications/reports/strategicplan.html for Minnesota, http://www.dnr.state.wi.us/org/water/MonitoringStrategy.pdf for Wisconsin, and http://www.michigan.gov/deq/0,1607,7-135-3313_3686_3731---,00.html for Michigan).

The three state programs use different strategies in their attempt to maximize the efficiency of their monitoring and assessment programs, although all are fundamentally similar in that a set of sentinel or index lakes is sampled on a regular basis. Index lakes were selected nonrandomly, for different reasons among states. In brief, all three states involve volunteers to monitor Secchi depth, which is an established indicator of either algal biomass or suspended sediment (Carlson and Simpson 1996). All three states are also developing additional volunteer programs to collect water samples for chlorophyll-*a* and/or nutrients.

In Minnesota, the DNR samples all large lakes (> 200 ha) on a 10-year cycle. Volunteers collect Secchi depth data on medium-sized lakes (40-200 ha). In addition, the Minnesota Pollution Control Agency (MPCA) conducts more intensive seasonal diagnostic studies at an unspecified number of lakes, based on need as indicated by either Secchi data or Landsat 7 satellite imagery (Kloiber et al. 2002a, b). Wisconsin DNR monitors 65 index lakes and 110 randomly selected lakes (without replacement) annually, on a six year rotation (WDNR 2005). In addition, volunteers measure Secchi depth on approximately 600 lakes. This volunteer program includes collection water samples for nutrients and chlorophyll-*a* on a subset of lakes. Michigan's program is similar to Wisconsin's in that it includes both index and randomly-selected lakes, but uses a 15 year rotation. Michigan volunteers monitor Secchi depth, total phosphorus, and chloroplyll-*a* on more than 300 lakes.

Wisconsin and Michigan are collaborating with Minnesota regarding the use of satellite imagery to supplement the transparency database. This technique has the potential to generate historical Secchi estimates, because past images and their spectral data are potentially available. In the future, the Network may find it useful to participate in this satellite imaging analysis of Secchi transparency to supplement lake data in remote areas.

2.1.3 Great Lakes Network Design

The Network examined the monitoring programs of the three states and weighed the advantages and disadvantages of different sampling designs. A summary of several sampling designs is included in Table 4. Consistency of the Network's monitoring design and protocol with neighboring state programs is desirable to facilitate data comparisons and allow statistical inferences using regional data.

The selection of lakes to include in the GLKN monitoring program must be based on the questions of interest, without jeopardizing the safety of field personnel. Development of detailed monitoring questions was an important initial phase that preceded the identification of target populations and subsequent development of sample designs. Question development was an iterative process with input from park managers, GLKN staff, and cooperating scientists. Our monitoring questions relate to individual lakes, lakes aggregated within each park, and lakes across the Network and region. As we began to develop the protocol, it became clear that we would not be able to address the questions regarding the general health of the lakes in a park or across parks in a statistically adequate manner while staying within our budget. Answering questions about all lakes within a park or all lakes across the Network requires either a complete census of lakes or a random selection of lakes, which allows inference to the population of lakes as a whole. A complete census of lakes is not feasible, as the Network contains well over 1,000 lakes (Table 5). A random selection of lakes is not desirable because many lakes are inaccessible and would require more than a day of off-trail, backcountry travel to reach.

This realization led to the design that will best provide for assessments of individual lakes. We will address questions at broader spatial extents through comparisons of trends across lakes. (See section 4, below, Data Management, Analysis, and Reporting, and SOP #9, Data Analysis, for more details).

We selected lakes at each park such that they are spatially distributed throughout each park and span gradients of chemical and physical parameters, visitor use, and watershed area. Some lakes are of particular interest to a park. If lakes are connected via stream or channel, we selected the downstream lake, as it serves as an integrator of its drainage system. The lakes included in the sampling design (Table 6), referred to as 'index lakes', will be sampled annually. Additional lakes will be sampled on a longer rotation at some parks as funding permits.

Table 4. Summary of different types of sampling designs.

	Random	Stratified	Systematic	Non-random
Lake	Sampled lakes are chosen randomly from geographic area	Randomly chosen from each geographic region (state, county, ecoregion) or within some other classification e.g., (recreational, beneficial use, drainage type, trophic status, surface area, max. depth)	Sample every lake along a transect, using a randomly chosen transect starting point	Choose lake based on convenience, access, proximity, or interest
Site	Randomly chosen from within the lake area	Randomly selected from within regions of lake	Sample at equidistant sites along transect of lake (distance selected *a priori*), starting with a randomly chosen point	Sample at the dam, over the deepest part of the lake, or other location based on interest
Depth	Randomly chosen	Randomly chosen within each depth region (e.g., epilimnion, hypolimnion, photic zone)	Sample at preset intervals, starting with a randomly chosen depth	Sample at the surface, at preset intervals surface to bottom, or at discreet depth for particular interest
Date	Randomly chosen	Randomly chosen within each season, month, or limnological period	Sample every two weeks, starting with a randomly chosen date	Sample on chosen day for reasons of convenience
Time	Randomly chosen	Randomly chosen within each diel period (e.g., morning, afternoon, evening), or some other division of day	Sample every two hours, starting with a randomly chosen time	Sample times based on convenience

Table 5. Summary of numbers of lakes and ponds in the six Great Lakes Network parks with inland lake resources, classified by size (surface area).

Park	Size class (ha)	Named Lakes	Unnamed Lakes	TOTAL > 1 ha
APIS	>1000	--	--	
	100-1000	--	--	
	10-100	1	--	
	1-10	2	7	
	<1	1	65	
	Total		76	10
INDU	>1000	--	--	
	100-1000	--	--	
	10-100	--	--	
	1-10	2	7	
	<1	--	49	
	Total	1	56	9
ISRO	>1000	--	--	
	100-1000	5	--	
	10-100	22	--	
	1-10	15	45	
	<1	--	189	
	Total	42	234	87
PIRO	>1000	--	--	
	100-1000	2	--	
	10-100	5	--	
	1-10	7	10	
	<1	2	96	
	Total	16	106	24
SLBE	>1000	1	--	
	100-1000	3	--	
	10-100	11	2	
	1-10	6	1	
	<1	6	3	
	Total	27	6	24
VOYA	>1000	4	--	
	100-1000	3	1	
	10-100	19	8	
	1-10	3	265	
	<1	--	237	
	Total	29	511	299

Table 6. Index lakes in the Great Lakes Network's sampling design. Maximum depth (Z_{max}) is included when known.

Park	Lake Name	Area (ha)	Z max (m)
APIS	Outer Island Lagoon	22	1.4
	Julian Bay/Stockton Lagoon	4	1.2
	Michigan Lagoon	3	1.3
	Little Sand Bay	0.8	--
	Total		4
INDU	Long	27	1.8
	Total		1
ISRO	Siskiwit	1635	46
	Desor	428	14
	Richie	216	11
	Feldtmann	186	3
	Sargent	143	14
	Harvey	55	4
	Beaver	20	5
	Ahmik	10	3
	George	3.8	3
	Total		9
PIRO	Beaver	310	10
	Grand Sable	255	26
	Chapel	28	42
	Legion	14	10
	Miners	5	4
	Total		5
SLBE	Manitou	104	14
	Florence	32	8
	Shell	41	4
	Bass (Leelanau County)	38	7
	Loon	37	20
	Round	6	8
	Total		6
VOYA	Shoepack	124	7
	Little Trout	97	29
	Locator	57	16
	Cruiser	47	28
	Peary	45	5
	Ek	36	6
	Brown	31	8
	Ryan	14	4
	Total		8

Apostle Islands National Lakeshore - One mainland and three island lagoons are included in the sampling design. These lagoons are shallow and may not always meet the EPA criterion of a lake (> 1m in depth; Baker et al. 1997), depending primarily on Lake Superior water level, but are of particular interest to the park because of recent evidence of high mercury levels throughout the food chain (J. Wiener, pers. comm). These four lagoons essentially comprise the park's inland lakes, as the remaining lentic waterbodies are transient beaver ponds.

Indiana Dunes National Lakeshore - Long Lake, which is shallow and polymictic, is the only lake included in the sampling design. Lake George, a relatively recently constructed lake, was sampled in 2006, but was deemed unsuitable because it is more of a lotic than lentic environment. One or more interdunal lagoons may be added to the sampling design, depending on preliminary sampling results, budget, and interest to the park.

Isle Royale National Park - We ordinated historical lake chemistry data (nonmetric multidimensional scaling via PCORD; McCune and Mefford 1999) and compared our results with those of Carlisle (2000; in Crane et al. 2006), who used both chemical and physical data, to determine types of lakes on the island. We then selected nine lakes, some from each quandrant of the ordination plots, ensuring they spanned the spatial extent of the island. The lakes also spanned gradients of recreational use, surface area, depth, and watershed area. The number of lakes selected is restricted largely by budget. As the park has concerns that water quality sampling may disrupt successful nesting of common loons (*Gavia immer*), an endangered species in Michigan, we will work with park staff to ensure water quality sampling personnel are trained in recognizing loon behaviors and avoid undue stress on nesting loons. In future years, additional lakes may be sampled on a rotational basis as funding permits.

Pictured Rocks National Lakeshore - Five lakes are included in the sampling design, spanning the spatial extent of the park. The selected lakes span gradients of surface area, depth, watershed area, and recreational use. If two or more lakes are connected (e.g., Beaver and Little Beaver Lakes), we selected the downstream lake as an integrator of that system. Additional lakes beyond the five index lakes may be sampled on a rotational basis, as funding permits. No lakes in the Inland Buffer Zone are included, nor were they considered, because the park does not own the land surrounding them. The Network will explore the possibility of sharing data with partners conducting monitoring of lakes in the Inland Buffer Zone.

Sleeping Bear Dunes National Lakeshore – Six lakes were selected as index lakes, based primarily on results of ordinations of past lake chemistry data (as described above for Isle Royale National Park). The lakes span the spatial extent of the park, as well as distance from roads and gradients of recreational use, surface area, and depth (watershed size is currently not known). Lakes that are partially within park boundaries but are actively monitored by other organizations were not considered so as to avoid duplication of effort. We will share data and expertise with these other organizations. Additional lakes beyond the index lakes may be sampled on a rotational basis, as funding permits.

Voyageurs National Park - Eight lakes were selected as index lakes based largely on a classification of lakes (Schupp 1992). The lakes have a long history of data collection, span a gradient of recreational pressure, and are spatially dispersed across the park. We selected

downstream lakes when one or more are connected via surface stream or channel. Water quality monitoring at the four large lakes (Namakan, Rainy, Sand Point, and Kabetogama) is currently base-funded by the park. Staff at VOYA conduct water quality monitoring of these lakes annually, twice a month, using methods comparable to those employed by Network staff. Therefore, the Network excluded these lakes from the design. In 2006, we sampled 22 inland lakes (excluding the four large lakes), and hope to sample all of these lakes, beyond the index lakes, on a rotational basis.

In summary, we will monitor the index lakes shown in Table 6 on an annual basis. Additional lakes will be sampled on a longer rotation as funding permits.

2.1.4 Legal Designations of Lakes Within the Great Lakes Network

All of the inland lakes in INDU, ISRO, PIRO, SLBE, and VOYA are designated as Outstanding Natural Resource Waters by their respective states. Many of these same lakes, however, are listed as impaired under section 303(d) of the Clean Water Act (CWA). All lakes in ISRO, PIRO, SLBE, and most lakes in VOYA are listed due to fish consumption advisories for mercury (NPS 2005, MDCH 2004, MPCA 2006). Additionally, Siskiwit Lake (ISRO) is listed due to fish consumption advisories for PCBs (NPS 2005). Little Sand Bay and Julian Bay (APIS) are intermittently connected to Lake Superior; when connected to the Great Lake, these lagoons are included on the 303(d) list for fish consumption advisories for PCBs (NPS 2005).

NPS-WRD has advised that newly-developed monitoring protocols include the water quality variables that have caused resource waters to be designated as impaired on the 303(d) list (Irwin 2005). GLKN is finalizing monitoring protocols for bioaccumulative contaminants, focused on bald eagles (*Haliaeetus leucocephalus*) (Route et al. 2008) and mercury in fish or other aquatic organisms (Wiener et al., in preparation). We expect to monitor inland lakes in the Network through these protocols on bioaccumulation.

2.2 Frequency of Sampling

A trade-off exists between the number of lakes sampled within a given year and the number of repeat visits made within a year. Variability of lake characteristics within a season is often high and may be comparable to the variability between years for some parameters, even for pristine lakes with no apparent long-term trends (e.g., Goldman et al. 1989).

Because of this seasonal variability, most state monitoring programs collect water quality data several times during the ice-free season, which usually extends from approximately May through October in the upper Midwest. Frequently collected data aid in understanding important issues, such as the onset of blooms of noxious algae and temporal patterns in temperature and dissolved oxygen.

Studies of annual and seasonal means of chlorophyll and total phosphorus concentrations in north temperate lakes spanning a range of trophic states (Hanna and Peters 1991, Marshall et al. 1988, Marshall and Peters 1989) led to the following conclusions:

- Sampling a single site per lake each visit was adequate to detect intra- or interannual trends; relatively little overall precision was gained by sampling multiple sites within a lake.

- Several visits within a year or within the open water season were required to characterize annual water quality as indicated by chlorophyll-*a*. Three to seven observations produced a coefficient of variation of 20% in oligotrophic lakes; 10 visits were needed for the same precision in more productive lakes.

- Differences between surface sampling and integrated euphotic-zone sampling were relatively small (also supported by Knowlton and Jones 1989). (In the GLKN region, only Michigan uses the euphotic zone sampling scheme and only for chlorophyll-*a*.)

- Sampling effort should be directed to more visits over the course of a season rather than increasing replication on a sampling date, given that characterizing seasonal or annual means is the goal.

Analyses of Vermont's Lay Monitoring Program data for total phosphorus (TP), chlorophyll-*a*, and Secchi depth (Schmeltzer et al. 1989) showed Secchi depth had the lowest variance of the three measures and therefore provided the most powerful ability to detect change over time. Chlorophyll-*a* was the most variable and TP was intermediate. The coefficient of variation (CV) of the long-term mean declined as a function of number of samples per year and the number of years of sampling for each variable, however increasing the sampling frequency beyond approximately four times per year yielded diminishing returns. Schmeltzer et al. (1989) also found that 10 years of TP or chlorophyll-*a* data would not provide a sufficiently precise baseline against which a 20% change could be statistically detected (*t*-test, $p < 0.05$ with a power of 80%; Figure 1). A 10-year baseline of Secchi data, collected once or twice a month, would permit a future 20% change to be detected (Figure 2). Larger changes (e.g., 40%) would be detectable for all three variables, after collection of 10 years of monitoring data.

Analysis of Minnesota Secchi data from many sets of lake data yielded a similar result to Vermont's (Heiskary and Lindbloom 1993). Ten years of monthly Secchi data will allow detection of a change of 20% for a given year from the 10-year baseline when $\alpha = 0.10$ and power $(1-\beta) = 0.90$ (MCPA 2005a, b). It is reasonable to expect somewhat less detectable trends in TP and chlorophyll-*a*, based on Minnesota's climatic similarities with Vermont and a similar abundance of glacial lakes in coniferous and mixed hardwood/coniferous watersheds, although detection levels cannot be precisely verified at this time.

Analyses of select data sets from Pictured Rocks and Sleeping Bear Dunes National Lakeshores shows a wide range in the amount of time required to detect change in dissolved oxygen (G. Host, unpublished data). One can expect to detect a trend in percent saturation of dissolved oxygen in defined depth strata after four to 19 sampling years (Table 7).

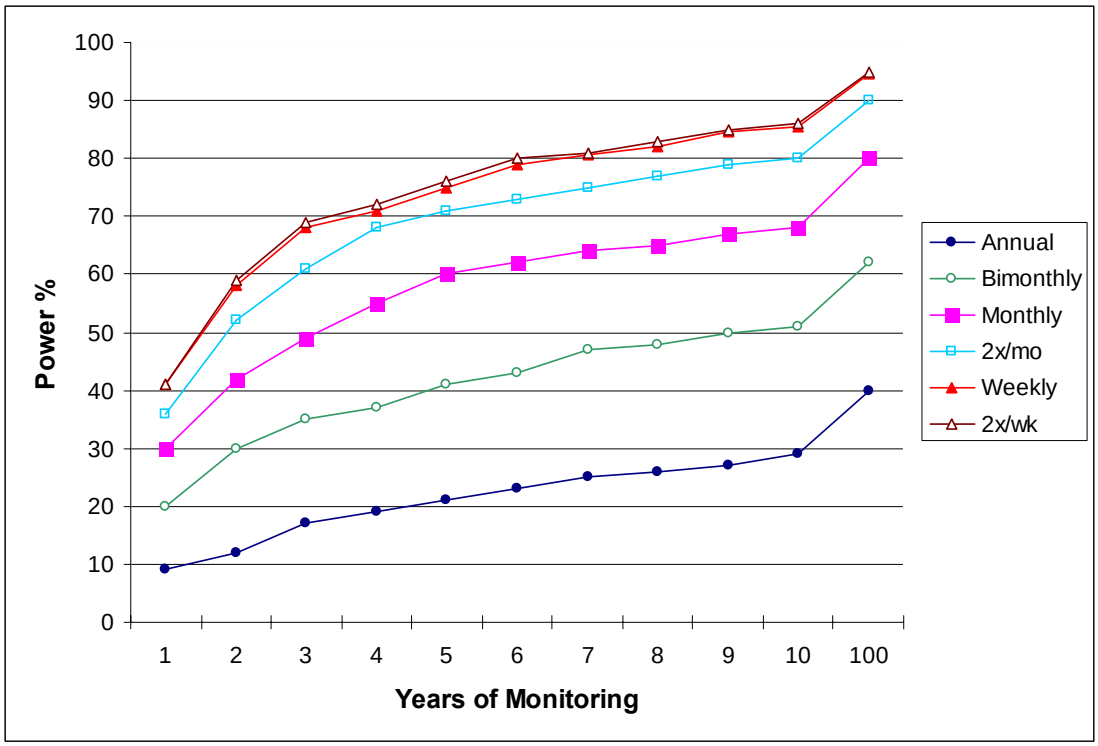


Figure 1. Trend analysis of long-term monitoring of total phosphorus in summer (Schmeltzer et al. 1989).

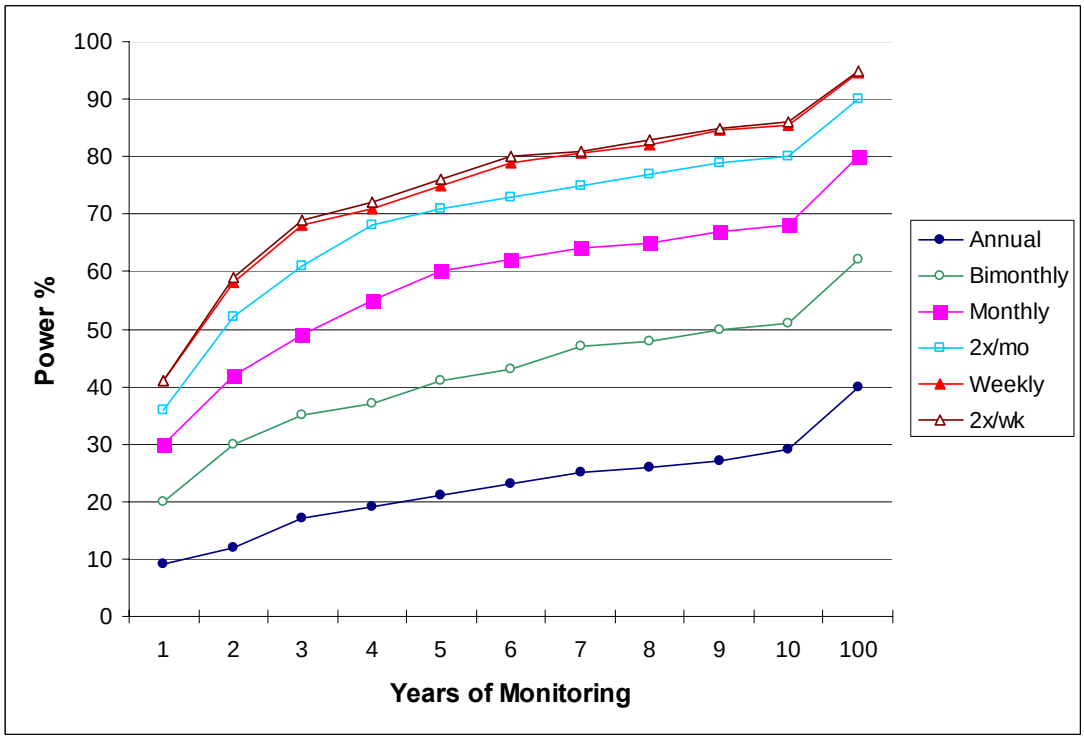


Figure 2. Trend analysis of long-term monitoring of Secchi depth in summer (Schmeltzer et al. 1989).

Table 7. Number of years required to detect a change in dissolved oxygen (DO) saturation in different Great Lakes Network lakes and depth strata. Calculations assume $\alpha = 0.1$, power $(1 - \beta) = 0.80$, rate of change = 20%, and sampling frequency of three times during the open water season. CV = coefficient of variation.

Lake (Park)	Depth Stratum (m)	Mean (% DO)	CV	# Years
Florence (SLBE)	1-3	96.8	0.051	4
Manitou (SLBE)	1-3	95.3	0.072	5
Manitou (SLBE)	6-7	87.8	0.065	5
Chapel (PIRO)	6-7	7.86	0.455	19

Sampling frequency requires a pragmatic compromise among statistical rigor, logistics, and cost. The Network will visit each sampling lake three times during the open water season when lakes are likely to be stratified. Analyses of existing data, such as those described above, help us understand the limitations of our sampling design. We do not expect to be able to detect changes in most variables after only a few sampling years, and realize that it make take many years to detect changes in some highly variable parameters. Given our sampling frequency, we expect even the least variable parameter to require more than 10 years of monitoring data before we will be able to detect a 20% change with 80% power.

2.3 Location of Sites

A single sampling site, typically located in the deepest part of the lake, will be the routine location for measuring all water quality variables. Sampling the deepest part of the lake allows sampling every possible depth to the bottom, and has a long history in limnology. Except for shallow lakes, this type of sampling ignores the littoral zone and always avoids the nearshore zone, as well as embayments and other features related to morphometry. In reservoirs, or in some lakes in which water levels are partially controlled, spatial variation across the length of the system, from inlet to outlet, typically forms major physical, chemical, and biological gradients that are important for understanding and managing the system (e.g., Wetzel 2001). Because the Network will not be sampling any large reservoirs, this spatial heterogeneity is not an issue for characterizing overall trends over time. Hanna and Peters (1991) have shown that a single sampling site per lake is adequate to characterize phosphorus and chlorophyll concentrations, given that each site is visited several times within a season.

2.4 Depths of Sampling

The depths of sampling for laboratory analyses of water chemistry varies widely among monitoring programs, ranging from multiple discrete depths and high frequency research programs, to the EPA-EMAP, EPA-NSWS (National Surface Water Survey), and EPA-NES (National Eutrophication Survey) snaphot surveys (Paulsen et al. 1998, Messer et al. 1991), in which water is collected at a single depth (primarily <1 m). In some EPA surveys, bottom water has been collected if the lake was thermally stratified. Some programs use a pump with an inlet tube that is raised and lowered to provide an integrated sample. The State of Michigan steadily lowers a glass bottle to twice the Secchi depth, collecting a single sample that integrates over the entire euphotic zone (MDEQ 1997). This integrated sample is used for chlorophyll-*a* in an

attempt to provide a better coupling between Secchi transparency and chlorophyll-estimated algal biomass (MDEQ 2001, 2004). Although conceptually reasonable, this procedure is questionable in that it adds some logistical difficulty to collecting the sample, it means that nutrients and chlorophyll are collected from different water masses, it potentially introduces errors associated with the qualitative nature of the bottle-filling process, and the euphotic zone is not necessarily twice the Secchi depth (Davies-Colley and Vant 1988, Lind 1979). In Minnesota and Wisconsin, a vertically integrated sample from 0 - 2 m is collected using a 2 m long plastic pipe. This type of sampler reduces the contribution of algae surface scums (MPCA 2004a, b) and collects an integrated column of water into a single sample. The main advantage of this integrated tube sampling device is that a larger stratum of water in the epilimnion is sampled, which reduces the effect that surface algal scums can exert on the seasonal chlorophyll means.

None of these techniques has achieved general acceptance among the community of limnologists. Because of its simplicity, many programs use a surface dip as a primary sample, assuming that the epilimnion is completely mixed and that the surface sample is a good estimator of epilimnetic conditions. Such assumptions are not always valid, particularly on warm, calm days when multiple thermal (and therefore chemical and biological) gradients may form for periods of hours to days (e.g., Moss 1998, WOW 2005).

Intensive sampling at multiple depths can best allow for calculating whole-lake nutrient budgets, if combined with morphometric data (lake shape, area, volume, maximum and mean depth, shoreline development, percent littoral zone, etc.). Carlson and Simpson (1996) pointed out, however, that this method may miss significant gradients, and that sequential sampling, with a randomized starting depth, can correct for this potential bias. Research programs that use such a costly sampling program, however, typically have background data and infer gradients from core suite profiles to best select sampling depths to minimize this source of error.

After considering all of the above sampling strategies, the Network decided to use a 0 - 2 m integrating tube sampler, following the protocol used by Wisconsin and Minnesota (WDNR 2004) and many other states. We will collect a near-bottom sample (~1 m from bottom) via Van Dorn sampler during mid-summer, when lakes are stratified, for analysis of TP.

2.5 Timing of Sampling

We will attempt to visit a given lake at approximately the same time of day each time we sample to minimize variation due to diurnal fluctuations.

3.0 Sampling Methods

This section summarizes the information presented in greater detail in the standard operating procedures (SOPs) #1 (Pre-Season Preparation), #6 (Field Measurements and Water Sample Collection), #7 (Processing Water Samples and Analytical Laboratory Requirements), and #11 (Post-Season Procedures). The section ends with an overview of quality assurance and quality control (QA/QC) procedures, which pertain to all aspects of sampling. The details of QA/QC are presented in SOP #12.

3.1 Field Season Preparations and Equipment Setup

(Summary of SOP #1: Pre-Season Preparations)

All details of field work need to be planned well in advance. Checklists help ensure that personnel, equipment, and supplies will be prepared in a timely and orderly manner. Table 8 summarizes which of the SOPs contain key checklists of equipment and supplies for water sampling. Field personnel should check the inventory of equipment and supplies against these lists to verify that no necessary equipment or supply is missing. All equipment, meters, and probes should be checked to verify that they are functioning properly. If needed, replacement equipment or supplies should be ordered well in advance of the onset of sampling, to allow time for inspection, pilot-testing, and calibration of replacements.

Table 8. Checklists of equipment and supplies for monitoring water quality of inland lakes.

Checklist	Location
Safety equipment and supplies	SOP #2
Decontamination equipment and supplies	SOP #5
Field equipment and supplies	SOP #6
Laboratory equipment and supplies	SOP #7

Table 9 provides general guidance for activities conducted prior to the field season. Additional considerations are as follows:

1) Copies of field information on waterproof paper should be kept in two types of 3-ring binders: a project binder and a site binder. The project binder should contain reference information relevant to general field sampling procedures with tabs identifying each procedure for easy access during field work, including QA/QC reminders, copies of all SOPs relating to safety, decontamination, sample collection and processing, copies of equipment instructions and troubleshooting, calibration logs (may be a separate binder), extra field forms, material safety data sheets (MSDSs) for field supplies that contain hazardous chemicals or materials, and analytical service request and chain-of-custody forms. Site binders should contain reference information specific to each sampling station, including a complete description of and directions to the monitoring site, location coordinates, maps, and photos, copies of previous field forms, and data tables summarizing all previous measurements of field variables and analytical laboratory

results. Both project binder and site binders should be taken along on each sampling trip, and thoroughly reviewed beforehand.

Table 9. Checklist of activities to be conducted prior to sampling inland lakes.

√	Activity	Approximate Date	Responsible Person
	Prepare calendar of planned field trips	Before Feb. 1	Project manager
	Review sampling methods	Jan. - Feb.	Project manager
	Review checklists of equipment and supplies	Jan. - Feb.	Project manager or crew leader
	Charge/replace batteries	Feb. and prior to each sampling day	Field personnel
	Clean and test equipment, repair or replace as needed	Jan. - Feb. and prior to each sampling day	Project manager or crew leader
	Prepare equipment blanks	Feb.	Project manager or crew leader
	Check expiration dates of reagents and calibration standards	Feb.	Crew leader
	Contract for lab analyses	Jan. - Feb.	Project manager
	Prepare list of items to be ordered; order supplies	Jan. - Feb.	Crew leader
	Train field personnel	Jan. - Feb.	Project manager
	Obtain permission for site access, if necessary	Feb.	Project manager or crew leader
	Confirm current research and collection permits	Jan. - Feb.	Project manager
	Check field vehicle for safety equipment and supplies	Feb. and prior to each sampling day	Crew leader
	Update site binders	Jan. - Feb.	Project manager or crew leader
	Prepare headers on field data forms, chain of custody forms, analytical service request forms; bottle labels	Prior to each sampling round	Crew leader
	Review sample collection, processing and documentation information	Feb. (Refer to SOPs #6 & 7)	Project manager and all crew personnel
	Notify contract analytical laboratory of planned sample shipments	Prior to each sampling round and day of shipment	Crew leader
	Make travel reservations and arrangements as needed	Feb. and prior to each sampling round	Project manager and crew leader
	Provide supervisor with field trip and check-in schedule	Prior to each sampling round	Crew leader

2) Field personnel should be adequately experienced or trained in using field and water quality sampling equipment. This experience is best obtained through a combination of classroom and hands-on training while pilot-testing equipment at a nearby waterbody. Personnel should be familiar with the instruction manuals, particularly with regard to calibration and maintenance procedures.

3) Meters and probes should undergo appropriate annual, weekly, and daily calibration. (See Table 13 for calibration frequencies and acceptance criteria.)

4) Conduct field reconnaissance, if necessary.

5) Pack all field gear to minimize shock and vibration during transport. Pack gear into organized and labeled boxes or cartons, to facilitate inventory and management of supplies.

6) Inspect motorized field vehicles to verify that they are tuned up and working properly. Ensure that vehicles meet space, power, and towing requirements.

3.2 Details of Taking Field Measurements and Collecting Samples

(Summary of SOP # 6: Field Measurements and Water Sample Collection)

3.2.1 Sequence of Activities During Field Workday

This subsection provides a general overview of all sampling tasks, while the next subsections contain more detailed descriptions of particular tasks. Following is the sequence of activities during any given field day:

1) Review the checklist of field gear.
2) Create a new field form for each monitoring station, printed on waterproof paper.
3) Sample bottles and labels should be prepared in advance and placed in a cooler.
4) Conduct daily calibration of appropriate meters and probes.
5) Inspect motorized field vehicles at the beginning of every field day, including all safety and directional lights, oil, gasoline, and tire air pressure levels.
6) Drive to boat landing. Load boat with sampling gear, launch boat, and navigate to monitoring site. Set up a clean work space on the boat for sampling.
7) Refer to description of monitoring station location, directions, and photo to verify correct location. Verify coordinates on GPS unit.
8) Measure field water quality variables and conduct sampling per SOP #6. Collect water sample from the highest nutrient depth last, which is usually the bottom sample.
9) Be sure that all samples are correctly labeled and preserved on ice.
10) Navigate to benchmarker and measure water level relative to marker, per SOP #4.
11) Verify that the field form is completely filled out, and initial the form.
12) If sampling from more than one monitoring station in a day, go back to step 7.
13) Upon return to shore, inspect boat, trailer, and all equipment that has come into contact with the water for invasive species. Follow procedures for decontamination of equipment per SOP #5.

14) Return to office or lab.
15) Clean sampling equipment per SOP #6. Rinse sensors with deionized water and perform calibration re-checks, as detailed in SOPs #6 and #12.
16) Conduct sample processing per SOP #7. Refrigerate or freeze samples, as required. Conduct in-house laboratory work and package samples for sending to contract analytical laboratory.
17) Enter data into NPSTORET as soon as possible after collecting field data and receiving results of laboratory analyses.

3.2.2 Arrival at Monitoring Site - Recording Field Information

Waterproof field forms should be prepared ahead of time, labeled with the project and station IDs. Field sampling information forms are used to record the physical and chemical water quality variables measured at the time of sample collection. In addition to recording the field variables, any samples collected for laboratory analyses must be so indicated. Documentation should include calibration data for each instrument, field conditions at the time of sample collection, visual observations, and other information that might prove useful in interpreting these data in the future.

Upon arrival at the sampling station, record general observations of the appearance of the water (e.g., water color and odor) and other information related to water quality and water use (e.g., fishing and swimming).

General observations should include information that will be useful in interpreting water quality information, such as:

- *Water appearance*. General observations on water may include color, unusual amount of suspended matter, debris, or foam.
- *Weather*. Recent meteorological events that may have impacted water quality include heavy rains, cold front, lack of precipitation, or heavy precipitation.
- *Biological activity*. Excessive macrophyte, phytoplankton, or periphyton growth. The observation of water color and excessive algal growth is important in explaining high chlorophyll-*a* values. Other observations to note include fish, birds, or spawning fish.
- *Unusual odors*. Examples include hydrogen sulfide, mustiness, sewage, petroleum, chemicals, or chlorine.
- *Watershed or in-lake activities*. Shoreline, inlet stream, or drainage-basin activities or events such as bridge construction, shoreline mowing, new construction, high densities of fast moving boats or personal water craft close to shore.
- *Other things related to water quality and lake uses.* If the water quality conditions are exceptionally poor, note that standards are not met in the observations (for example, dissolved oxygen is below minimum criteria). Uses may include swimming, wading, boating, fishing, irrigation pumps, or navigation. This type of information may be used in evaluating standards compliance.

While at each monitoring site, the information recorded on field data sheets should include:

- Date
- Time of arrival
- Names of field team members

- GPS coordinates, to verify location
- Current weather (air temperature, wind speed and direction, wave height) and relevant notes about recent weather (storms or drought)
- Observations of water quality conditions
- Description of any photographs taken
- Multiprobe (model), calibration date, and field measurements of core suite variables
- List of samples collected and collection times for advanced suite variables or quality assurance samples and method of collection (e.g., integrating tube or grab)
- Whether any samples were not collected, and reason
- Water level measurement
- Any other required metadata for STORET data entry
- Time of departure

All entries should be made clearly. If an incorrect entry is made, a single heavy line should be drawn through the incorrect entry and the correction made. All corrections should be initialed and dated. The completed field forms will be maintained in chronological order by station, copied into project binders and the originals maintained on file indefinitely. Field data are reviewed annually by network personnel (see SOP #8, Data Entry and Management, for details).

3.2.3 Measurement of Field Parameters

Field measurements must be collected from an undisturbed area, and multiprobe instruments must be allowed to stabilize (Table 10). Take a replicate reading for every 10 readings; values should agree within 10% or the acceptance criteria in Table 10, whichever is larger. Use a Secchi disk and/or transparency tube to measure the water clarity.

3.2.4 Collection of Water Samples

Collect water sample(s) with an integrated sampling tube for 0-2 m samples and Van Dorn for near-bottom samples. In the field log book and on the field data sheet, record information related to the sample collection, including:

1. Lake name and site identification code.
2. Sample date, time, and depth.
3. The amount of sample collected.
4. Whether duplicate samples for quality control were collected at this site.
5. Any additional notes or observations pertinent to this sample or location for this sampling period.

Always keep the following in mind:

- Sample containers should be labeled in indelible ink with, at a minimum, the station name, date and time of collection, and preservation method, if applicable.
- To ensure the integrity of the sample, be aware of possible sources of contamination. Contamination introduced during each phase of sample collection and processing is additive and usually is substantially greater than contamination introduced elsewhere in the sample handling and analysis process.
- Use appropriate procedures and quality-assurance measures that ensure sample representativeness and integrity and that meet study criteria. The degree to which a

sample can be considered representative of a waterbody depends on many interrelated factors including temporal and spatial homogeneity of the waterbody, sample size, and the method and manner of sample collection.

Table 10. Typical sensor performance specifications (Penoyer 2003).

Sensor	Expected Range	Reporting Resolution*	Estimated Bias	Stabilization Criteria
Temperature	-5 to 45°C	0.01°C	±0.15°C	Thermistor: ± 0.2°C Glass: ± 0.5°C
Specific Conductivity (SC25)	0 to 2000 µS/cm	µS/cm (range dependent)	±0.5% of reading + 1 µS/cm	≤100 µS/cm: ± 5% >100 µS/cm: ± 3%
PH	1 to 14 units	0.01 unit	±0.2 units	± 0.1 standard unit
Dissolved Oxygen (Conc.)	0 to 50 mg/L	0.01 mg/L	0 to 20 mg/L: ±0.2 mg/L 20 to 50 mg/L: ±0.6 mg/L	± 0.3 mg/L
Dissolved Oxygen (% sat.)	0-200%	0.1%	~ ±2 %	± 2 %
Depth – Z (pressure sensor)	0 - > 100 m	0.1 m	~ 0.1 m	0.1 m

* Resolution specifications are supplied by the manufacturers of the measuring meters. They are not necessarily closely related to real-world (outdoor) precision or bias, and are sometimes more related to the number of significant figures reported rather than how accurate the extra significant figures are. This is why we will control measurement sensitivity in the actual outdoor measuring environment at least once a year by calculating alternative measurement sensitivity (AMS; see Irwin 2006 for more details on AMS).

3.3 Post-Collection Sample Processing

(Summary of SOP #7: Processing Water Samples and Analytical Laboratory Requirements)

Upon return to the office or home base, conduct in-house laboratory work, prepare and ship sample bottles, clean and prepare equipment for storage, and enter data from field forms into NPSTORET.

3.3.1 In-house Laboratory Work

Upon return from the field, keep samples bottles refrigerated prior to processing or analysis.

Process samples according to SOP #7 and specific laboratory instructions. If any of the water quality analyses are done in-house (for example, alkalinity titrations), conduct these procedures as soon as possible after returning from field work, ensuring that the maximum holding times for these variables are not exceeded. Store processed samples in the refrigerator or freezer, as appropriate, until shipping to the contract laboratory.

3.3.2 Shipping Samples to Contract Laboratory

Prior to shipping samples, notify the laboratory of how many samples of what type and when to expect shipment. Ensure that laboratory personnel will be available to receive the shipment. Check that the sample bottles are correctly labeled according to the protocols of the contract laboratory and that caps are securely tightened. Complete the analytical services request and chain-of-custody forms provided by the laboratory. Pack samples carefully in the shipping container according to laboratory protocols, to prevent bottle breakage, shipping container leakage, and sample degradation.

Table 11 summarizes the variety of methods, detection limits, preservation techniques, and holding times for water samples addressed by this protocol. Methods conform to those used by Minnesota, Wisconsin, and Michigan for state certification of environmental laboratories involved in Clean Water Act or drinking water sample analysis (MDH 2005, WSLH 2003, MDEQ 2005). They are also used by EPA-funded research projects of natural waters in the upper mid-western United States. Refer to SOP #6 for additional details regarding sample collection and preservation.

The selection of a contract laboratory will include criteria regarding the laboratory's ability to provide method limits of quantitation (ML) adequate for the dilute, oligotrophic lakes included in this monitoring protocol. Desired MLs and method detection limits (MDL) for water chemistry parameters are based on examination of historical data, the occurrence of low nutrient lakes in several of the parks, and the MDLs achievable using the standard water chemistry methods that research limnologists currently use. See SOP #12 for details regarding analytical detection levels required for GLKN water quality monitoring.

3.3.3 Equipment Cleaning and Storage

Clean all sample collection and storage containers and labware in a 0.1N HCl acid bath followed by deionized water rinses per SOP #7. Monitoring equipment should be cleaned and packed for storage. Keep equipment and supplies properly organized and labeled so they can easily be inventoried using the checklists.

3.3.4 Data Entry and Management

Download or enter field and laboratory data into appropriate spreadsheets and databases as soon as possible to minimize error, per SOP #8. Refer to the instrument manufacturer's instruction manual for details on downloading data from field dataloggers.

Table 11. Example range of analytical methods, method detection limits (MDLs), containers, preservation methods, and holding times.

Analyte	Analytical *Note 1*	Method #	Det. Limit	Vol. (ml)	Filter	Preservation	Sample Bottle *Note 2*	Hold Time
Alkalinity	Titrimetry	310.1 EPA-NERL	10 mg/L			4°C		14 days
	Spec. auto.	310.2 EPA-NERL	10 mg/L			4°C		14 days
	Titrimetry	NFM USGS-OWQ	0.01 meg/L		*Note 4*	None		none
Calcium	ICP	3120B APHA	10 ug/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
	Titrimetry	215.2 EPA-NERL	0.5 mg/L		*Note 3*	4°C		6 mos
	FAA	I-3152 USGS-NWQL	0.1 mg/L	250 mL	*Note 3*	pH<2 HNO_3	P	180 day
Chloride	IC	300.0 EPA-NERL	0.02 mg/L			4°C	P or G	28 day
	Colorimetry	325.2 EPA-NERL	1 mg/L			4°C		28 day
	Titrimetry	4500-Cl APHA	0.15 mg/L	100 mL		4°C	P or G	28 day
Chlorophyll-a	Spect.	10200 APHA	2 ug/L	≤ 1 L	*Note 4*	Freeze filter	P	30day
DOC	Spect.	415.3 EPA	0.018 mg/L	125	*Note 3*	pH<4 H_2SO_4	G	28 days
	Spect.	0-1122-92 USGS	0.1 mg/L			4°C	AG	
K	ICP	3120B APHA	0.3 mg/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
	FAA	3111B APHA	5 ug/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
Mg	ICP	3120B APHA	20 ug/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
	FAA	3111B APHA	0.5 ug/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
Na	ICP	3120B APHA	30 ug/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
	FAA	3111B APHA	2 ug/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
NH_4-N	Selective elec.	4500-NH_3E	0.08 mg/L			4°C/pH2,0°C		24h/28d
	Colorimetry	350.2 EPA-NERL	0.08 mg/L			pH<4 H_2SO_4		28 day
	Titrimetry	4500-NH_3 APHA	5 mg/L			4°C/pH2,0°C		24h/28d
SiO_2	ICP	3120B APHA	20 ug/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
	Spect.	4500- SiO_2 D APHA	0.04 mg/L		*Note 3*	No, 4°C	P	28 days
	FIA-Spect.	4500- SiO_2 F APHA	0.78 ug/L		*Note 3*	No, 4°C	P	28 days
SO_4	IC	4110C APHA	75 ug/L		*Note 3*	pH<4 H_2SO_4	P or G	
	CIE-UV	D6508 ASTM	0.1 mg/L		*Note 3*	pH<4 H_2SO_4		ASAP
	Spect.	37512 EPA-NERL	0.5 mg/L		*Note 3*	pH<4 H_2SO_4	P or G	28 days
TP	Spect.	I-2606 USGS-NWQL	0.001 mg/L	125 mL		MgCl 4°C	BrownP	30 days
	Alkaline P	USGS 2003	0.01 mg/L	120 ml	*Note 5*	4°C /H_2SO_4		48 h/30d
	ICP	200.7 EPA-NERL	60 ug/L			pH<2 HNO_3	P	6 mos
TN	Alkaline P	USGS 2003	0.03 mg/L	120 ml	*Note 5*	4°C /H_2SO_4		48 h/30d
	Titrimetry	4500-N	0-100 mg/L			4°C	AG	7 days
	Combustion	440.0 EPA-NERL	0.1 mg/L			Filter		100 day

Source: National Environmental Methods Inventory website (NEMI 2006)

This list is not an endorsement of any particular method or laboratory for any particular analyte. Rather it is to be used as a reference for the range of analytical methods available for each analyte. There are surface water conditions (pH, turbidity, other elements) that make a particular method unsuitable for a particular situation. As GLKN is monitoring surface water, the methods listed were chosen as representative of the lower range of detection limits.

Note 1. CIE-UV= capillary ion electrophoresis with UV detection, FAA = flame atomic absorption, FIA = flow injection analysis, IC= ion chromatography, ICP = inductively coupled plasma, Spec. auto = spectroscopy with autoanalyzer

Note 2. P = plastic (polypropylene), G=glass, AG=amber glass

Note 3. 0.45µm membrane filter. Pre-filter for dissolved portion analysis.

Note 4. 0.45µm glass fiber filter.

Note 5. USGS 2003. Evaluation of Alkaline Persulfate Digestion as an Alternative to Kjeldahl Digestion for Determination of Total and Dissolved Nitrogen and Phosphorus in Water By Charles J. Patton and Jennifer R. Kryskalla. U.S. Geological Survey Water-Resources Investigations Report 03-4174.

3.4 End of Field Season Procedures

(Summary of SOP # 11: End-of-Field Season Procedures)

When sensor probes are to be stored for extended periods of time, thoroughly clean sensors, remove batteries, and store the sonde according to specific instructions in SOP #11 and the manufacturer's manual. Store calibration standards and electrolyte solutions in a temperature-controlled environment. Ensure that containers are dated upon receipt and upon opening; observe expiration dates.

3.5 Quality Assurance/Quality Control

The objective of quality assurance/quality control (QA/QC) is to ensure that the data collected for a project are meaningful, representative, complete, precise, accurate, comparable, and scientifically defensible (O'Ney 2005a). It is a broad management concept requiring the complete integration of field and laboratory systems of sample collection and analysis. The QA/QC procedures that pertain to sample collection and processing are focused on: 1) ensuring that any given field or laboratory measurement accurately represents the water resource at the time the sample was collected, 2) ensuring that water quality data are comparable across all sampling dates, and 3) verifying that no contamination has been introduced to the sample at any time. These activities range from instrument calibration, to specification of field methods and laboratory detection limits, to analysis of sample blanks and spikes. Table 12 summarizes the QA/QC procedures pertaining to sampling methods that will be followed in this protocol.

One important aspect in the accuracy and precision of a water quality monitoring program is the correct selection of probes for measuring field variables and their subsequent calibration and maintenance schedule. Table 10 (above) lists typical field sensor performance specifications that should be expected from monitoring equipment for this protocol. Table 13 summarizes the ideal calibration frequency and minimum acceptance criteria for these sensor probes. The reality of logistical constraints at back country sites may preclude calibration and checks of calibration at the ideal frequency. Calibration logs for multi-parameter sondes will be maintained and will document the frequency of calibration and calibration checks. Ensure calibration standards are not used beyond expiration dates. Refer to SOP #6 for guidelines on potential field measurement problems.

The detection limits for water quality variables specified in Table 11 are based on examination of historical data and the occurrence of dilute concentrations of water quality variables in natural waters. Many commercial laboratories do not routinely analyze samples using these lower detection limits, even if they have the proper instrumentation, because their primary work load is wastewater-related with much higher concentrations. Therefore, the process of selecting a contract analytical laboratory will include consideration of whether the lab has experience analyzing naturally dilute waters.

Quality Control (QC) involves specific tasks undertaken to determine the reliability of field and laboratory data. It is accomplished internally by routine analysis of blanks, duplicates, and spikes in the day-to-day operation of a laboratory, or externally by incorporating field-originated blanks, duplicates, and spikes into the set of the samples collected during a water quality survey. We will include the following QA/QC routines:

1) Equipment blanks prior to the field sampling, to ensure no extraneous sources of contamination are introduced into the samples.
2) Submit duplicate water samples, at the rate of approximately 10%, so that the reported data are precise, or the results of analyses are reproducible.
3) Document the sensitivity of multiprobes through an estimation of the limits of detection known as alternative measurement sensitivity (AMS).
4) Replicate multiprobe field measurements at the rate of approximately 10%. Calculate the relative percent difference to document precision of the multiprobe.

Table 12. Summary of QA/QC procedures pertaining to sampling methods.

Procedure	Description/reason
Instrument calibration logs	Each instrument must have a calibration log. Calibration schedule must be observed, using fresh calibration standards.
Project binder	Containing: checklist of QA/QC reminders, copies of decontamination, sample collection and processing SOPs, copies of equipment calibration and troubleshooting instructions, ASR and COC forms, blank field forms.
Site binders	Containing: GPS coordinates for verification of correct sampling location, table of previous field measurements to compare with new measurements, map and directions to site.
Field forms	Field forms are the only written record of field measurements, so copies are placed in project binders and originals must be kept on file indefinitely.
Field instrument methods	Require consistent measurement methods and detection limits
Sample preservation and minimum holding time	Water samples are maintained as close to sampling conditions as possible.
Chain-of-custody	A chain-of-custody includes not only the form, but all references to the sample, including information that allows tracing the sample back to its collection and documents the possession of the samples from the time they were collected until the sample analytical results are received.
Laboratory methods	Require consistent analytical methods and detection limits

Table 13. Ideal calibration frequencies and acceptance criteria for field instruments.

Parameter	USEPA Method	Minimum Calibration Frequency and QC checks	Acceptance Criteria	Corrective Actions
Temperature thermometer:	170.1	Annually, 2-point check with NIST thermometer	±1.0 ºC	Re-test with a different thermometer; repeat measurement
Temperature thermistor:	170.1	Annually, 2-point check with NIST thermometer	±1.0 ºC	Re-test with a different thermometer; repeat measurement
Specific Conductance (SC25)	120.1	Daily, prior to field mobilization; calibration check prior to each round of sampling; 10% of the readings taken each day must be duplicated or a minimum of 1 reading if fewer than 10 samples are read.	±5% RPD 10%	Re-test; check low battery indicator; use a different meter; use different standards; repeat measurement
pH	150.1	Daily, prior to field mobilization (two buffers should be selected that bracket the anticipated pH of the water body to be sampled with an independent third buffer selected to check instrument performance in that range); Calibration check w/ third buffer prior to each round of sampling 10% of the readings taken each day must be duplicated or a minimum of 1 reading if fewer than 10 samples are read.	±0.05 pH unit ±0.1 pH unit RPD 10%	Re-test; check low battery indicator; use different standards; repeat measurement; don't move cords or cause friction/static
Dissolved Oxygen	360.1	Daily, prior to field mobilization; check at the field site if elevation or barometric pressure changed since calibration	0.2 mg/L concentration or ±10% saturation	Re-enter altitude; re-test; check low battery indicator; check membrane for wrinkles, tears or air bubbles; replace membrane; use a different meter; repeat measurement; allow more time for stabilization
Depth	--	Daily, prior to field mobilization, check at the field site. Check annually against commercially purchased brass sash chain labeled every 0.5 m to ensure that it reads zero at the surface and varies <0.3 m for depths <10 m and no more than 2% for greater depths.	±0.1 m	Retest, check low battery indicator; repeat measurement; use with accurately calibrated line
Transparency tube	--	Transparency tubes have a 100 or 120 cm scale; ensure tube is clean	±1.0 cm for transparency tube	Transparency tube
Marked lines (e.g., Secchi, Van Dorn)	--	Check markings annually against brass sash chain. If lines are heated (for decontamination) check prior to each round of sampling.	±1%, 0–10 m ±2%, >10 m	Re-mark line.

4.0 Data Handling, Analysis, and Reporting

4.1 Metadata Procedures

Metadata allows potential data users to evaluate the quality and usefulness of the data based on an understanding of the complete process under which it was collected and maintained. In this respect, all of the protocol documentation, including standard operating procedures (SOPs), is part of a dataset's metadata. A reference to the appropriate version of these documents is part of the metadata for any particular element of a dataset. Although perhaps obvious, all data must have an associated value for the date and time they were collected.

Most of the remaining metadata will be recorded directly in the protocol-specific databases and tables. We will enter all required metadata for NPSTORET; the data and metadata will ultimately be moved to the EPA STORET database.

For metadata associated with geospatial data, we will abide by Executive Order 12906, which mandates that every federal agency document all new geospatial data it collects or produces using the Federal Geographic Data Committee (FGDC) Content Standard for Digital Geospatial Metadata (CSDGM; www.fgdc.gov/metadata/contstan.html). All GIS data layers will be documented with applicable FGDC and NPS metadata standards. The Network will also generate FGDC-style metadata for non-spatial datasets that meet this standard, absent only the geospatial-specific elements.

Although it is not required, we will make every effort to complete Biological Data Profiles (www.fgdc.gov/standards/status/sub5_2.html) for appropriate datasets and add associated metadata to the National Biological Information Infrastructure (NBII; www.nbii.gov/datainfo/metadata) Clearinghouse.

For more details on the Great Lakes Network's overall strategy for metadata generation, management, and distribution see chapter 8, Data Documentation, of GLKN's Data Management Plan (Hart and Gafvert 2005) and the appendices of that document.

4.2 Overview of Database Design

The NPS-WRD has established a policy that all I&M water quality monitoring data will be made compatible with, and be uploaded to, the EPA's STORET database. The WRD developed a Microsoft Access database tool, NPSTORET, which duplicates most of the data and table structures in EPA STORET, to facilitate easier movement of I&M networks' water quality data into EPA STORET format. We will use NPSTORET as the primary data entry tool, and data transfer mechanism to WRD.

In addition, GLKN uses the Vital Signs Internet Mapping Service (VSIMS) for data distribution. This service allows users to explore and query monitoring data using spatial and non-spatial parameters. Network versions of NPSTORET are used to update a master version of STORET maintained by NPS-WRD. The WRD master copy of STORET data is the data source that is used by the VSIMS to serve water quality data collected by GLKN and other I&M networks.

The Great Lakes Network will maintain one master copy of NPSTORET at the Ashland office on a central server. This is the only copy of NPSTORET that can be used to export data to other locations (WRD). Additional copies of NPSTORET can be used by Network staff or cooperators, but they can only be used as a conduit for data entry and the importation of data to GLKN's master version of NPSTORET. For analysis, the data from the master copy of NPSTORET, or the mirrored tables in VSIMS must be used.

4.3 Data Entry, Verification, and Editing

Detailed instructions for the data entry procedures for this protocol are given in SOP #8, Data Entry and Management. As described above (section 3, Field Methods), three general classes of water quality data are collected. The first is field observations and measurements that are recorded on data sheets in the field. These field sheets will be entered into a digital form in NPSTORET. The second class of data is the results of testing performed by contract analytical laboratories. An import routine will be created in GLKN's version of NPSTORET to bring in laboratory results and to run QA/QC checks. The last class of water quality data is digital data that have been collected by multiprobe sondes and other field data loggers. Import routines in GLKN's version of NPSTORET will also be developed for these digital files.

Data verification starts with the QA/QC steps that are outlined in the SOPs associated with this protocol. If data being entered into NPSTORET do not pass a QA/QC test, NPSTORET prompts the user to make corrections and re-enter the data. Data that are outside the expected rate of change for a parameter based on previous records for that parameter will be flagged for further review by an expert.

Quality assurance/quality control checks are performed as data are entered into NPSTORET and again when the data are transferred to WRD. The Network's water quality data records are regarded as being in provisional status until they are returned to GLKN from WRD, or are accepted by WRD without changes after the final QA/QC steps. Only qualified users who have been trained and given edit permissions are allowed to edit data in NPSTORET. These procedures protect the integrity of the data and allow the history of each data record to be traced.

4.4 Data Archival Procedures

Data archiving serves two primary functions: it provides a source to retrieve a copy of any dataset when the primary dataset is lost or destroyed, and it provides a data record that is an essential part of the QA/QC process. The unedited files are the original data for digital data. The archival of the printed data forms for this protocol is described in SOP #8.

The Network will create duplicate files of all digital data at the earliest opportunity. At least two complete copies of any water quality dataset are required by WRD, including digital replicas (scanned versions) of hard copy data sheets. Digital field data that are entered directly into a field computer or collected from a data logger will be backed up to a second medium at the earliest possibility. The data files on field computers and loggers must not be erased until the integrity of these data files are verified on the duplicate storage medium.

The Network's master version of NPSTORET is maintained on a central server in the Ashland Office that is backed up daily, and backed up off-site weekly. Complete details of the GLKN Server archiving procedure are found the Infrastructure chapter of GLKN's Data Management Plan (Hart and Gafvert 2005); the general strategy for data archiving is also described in this plan and its appendices.

4.5 Quality Assurance and Quality Control Pertaining to Data Entry and Management

Quality assurance and quality control procedures are crucial during every step of data entry and data management. Details of such QA/QC regarding data management are provided in SOP #8 and are summarized below in Table 14.

Table 14. Summary of QA/QC procedures pertaining to data management.

Procedure	Description
Instrument calibration logs	Each instrument must have a calibration log.
Field forms	Field forms are the only written record of field measurements, so copies are placed in project binders and originals must be kept on file indefinitely.
Estimating precision	The precision measurement is calculated using the Relative Percent Difference (RPD) between duplicate sample results per analyte. Precision estimates should be performed within 7 days of receipt of laboratory results.
Electronic data entry	Approximately 10% of electronic data entries should be spot checked on a random basis for errors. If errors are found, another 10% are spot checked.
Data archiving	Program sampling data and associated records are archived in boxes and stored at the GLKN Ashland office. Boxes are numbered consecutively by year, project, and station number.
Data validation	Data validation is the process that determines whether data collection quality control objectives were met.
Data validation reports	Data validation reports provide a narrative that discusses any deviations from QA/QC procedures and the impacts of those deviations.
Data verification	Data verification demonstrates that a data set will qualify as credible data.
Data verification reports	Data verification reports document the results of the data verification procedure.
Data qualification codes	Data must be fully qualified before uploading to the Water Resources Division

4.6 Routine Data Summaries

Brief characterizations of the data from each lake, across each NPS unit in which sampling occurred and for the network as a whole, will be performed following each sampling year after all QA/QC procedures have been completed. For each water quality variable, these descriptive statistics will include mean, median, maximum, and minimum values by lake; and these same values with the addition of skew, kurtosis, and measures of variability (e.g., coefficient of variation, standard error, 95% confidence intervals) among lakes within each NPS unit. These broader-extent analyses can inform managers whether anomalous values recorded from a given lake (or even across all lakes within one park) were also observed at broader spatial extents that year (e.g., across a given park, or in other parks). Given the relevant legislation (e.g., Clean Water Act of 1972), it may be of interest to the individual parks and to other entities to assess the proportion of measurements during a time period or across a domain (at a single point in time) that exceed specific water quality criteria or pre-determined thresholds. As with nearly all percentage data, arcsine transformations must be performed on those percentage data before statistical analyses can be performed. However, back-transformed values will be used for graphical presentation and other reporting.

In addition to these descriptive statistics, analytical approaches may also include estimation of interannual change, graphic approaches (e.g., comparison of mean and variability in a parameter in the current year versus past years), and occasionally qualitative analysis (Guthery et al. 2001), as well as modeling, correlational analyses, and various parametric and nonparametric analyses.

4.7 Methods for Long-Term Trend Analysis

After at least three sampling seasons of monitoring data are collected at a given lake, more intensive analyses of change will be performed for each lake. In addition to repeated-measures, time-series, regression, and non-parametric equivalents of various methods such as Mann-Kendall, monitoring data may also be evaluated through Monte Carlo simulation analyses, Bayesian analyses, and comparisons of period means. For the latter-most approach, one is often interested in comparing values before and after an important event (e.g., change in management policy, remarkable anthropogenic disturbance, natural catastrophe, drought), and considers years within each of the two periods as replicates. The seasonal Kendall test is one of several preferred nonparametric tests for evaluating interannual trends in water quality (Hirsch et al. 1991). The test, which accounts for intra-annual variability, has been used widely for more than 15 years, and usually requires five to ten years of data. In the test, one can define ‘seasons’ as months, quarters, ice-on/off periods, by limnological stratification, or by any other criterion. The examination of interannual change is subsequently performed on each of the seasons; the average of all the seasons’ slopes becomes the final trend line. Trends in parameters that are analyzed with respect to biotic and abiotic covariates that may affect water quality will be examined, although cause-effect relationships may be investigated more thoroughly by NPS partners and collaborators (e.g., USGS-WRD, university investigators).

In addition to analyzing each variable separately, several abiotic indicators of water quality that are not correlated and that naturally could be considered a homogeneous group of parameters could be analyzed collectively through multivariate ordinations (e.g., nonmetric multi-

dimensional scaling) of resource conditions through time, following West and Yorks (2002). This approach effectively integrates information across many indicators, and can suggest whether water quality at individual lakes is moving in the same direction in multidimensional ordination space. Furthermore, joint plots can be overlaid on the ordination, and can suggest which variables correlate most strongly to the direction of changes. Multivarite analyses can help suggest cause-and-effect relationships and are useful as hypothesis-generating tools. Multivariate ordinations are also useful for relating water-quality conditions with abundance or presence data from many species (e.g., diatoms) (McCune and Grace 2002).

See SOP #9 for additional details on data summaries and analyses.

4.8 Reporting Schedule

One of the Network's main goals is to ensure that the results and knowledge acquired through the water quality monitoring program are shared with all appropriate parties, especially the parks and their natural resource managers. We will strive to provide park managers with clear, meaningful products in a timely manner to convey our findings. Because our monitoring data will be of interest to a broader community, we will also provide our reports to the states, the NPS I&M Program, and when appropriate, submit them to peer-reviewed journals for publication. We will also present our findings orally and in poster format at regional meetings, such as the Western Great Lakes Research Conference, the St. Croix Research Rendezvous, or the Lake of the Woods Research Conference.

As mentioned above, routine data summaries will be conducted annually for lakes and parks that are sampled within that year. Annual summary reports will be produced, with the primary audience being the parks.

More comprehensive reports, with analyses of trends, will occur after three or more seasons of sampling. For stations that are located where no previous monitoring has occurred, three sampling periods are the minimum needed to establish a time series sufficiently powerful to detect meaningful levels of change (e.g., 20%) through time.

The target audience of the analysis and synthesis reports will be the parks, the Network, both regional and Servicewide I&M, and the broader scientific community. Drafts of these reports will be reviewed internally and sent to the parks, and possibly outside sources, for further review. The extent of review will depend on how analytically complicated the methods are and the gravity of inference and recommendations.

4.9 Report Format with Examples of Summary Tables and Figures

Both annual summaries and reports that include detailed analyses on trends should follow the format of a typical peer-reviewed journal article. The following outline is a good example of the type of report to be produced.

TITLE PAGE (Title, Author(s), Participating Institutions, For Whom Prepared, and Date)
TABLE OF CONTENTS PAGE
EXECUTIVE SUMMARY PAGE (abstract)

1.0 INTRODUCTION
- 1.1 Background
- 1.2 Justification for Study
- 1.3 Objectives

2.0 METHODS
- 2. 1 Study area(s)
- 2.2 Field method(s)
- 2.3 Analytical method(s)

3.0 RESULTS
4.0 DISCUSSION
5.0 MANAGEMENT IMPLICATIONS
6.0 ACKNOWLEDGEMENTS
7.0 LITERATURE CITED (if any)
8.0 TABLES
9.0 FIGURES
10.0 APPENDICES (if any)

Reports should include tabular and graphic displays of data. Tables are appropriate for displaying simple data summaries, such as data collected within a season at one park, but can also be used to show results of more comprehensive analyses. Graphical display of data is especially useful for depicting trends across years (Figures 3 and 4) or the correlation between two variables. See SOP #10 for additional details on report format and presentation of data.

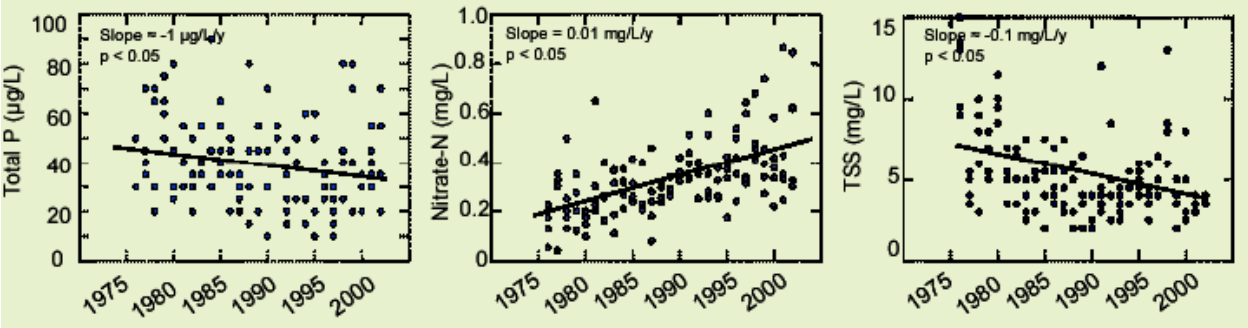


Figure 3. Examples of seasonal Kendall trend plots for three water quality variables.

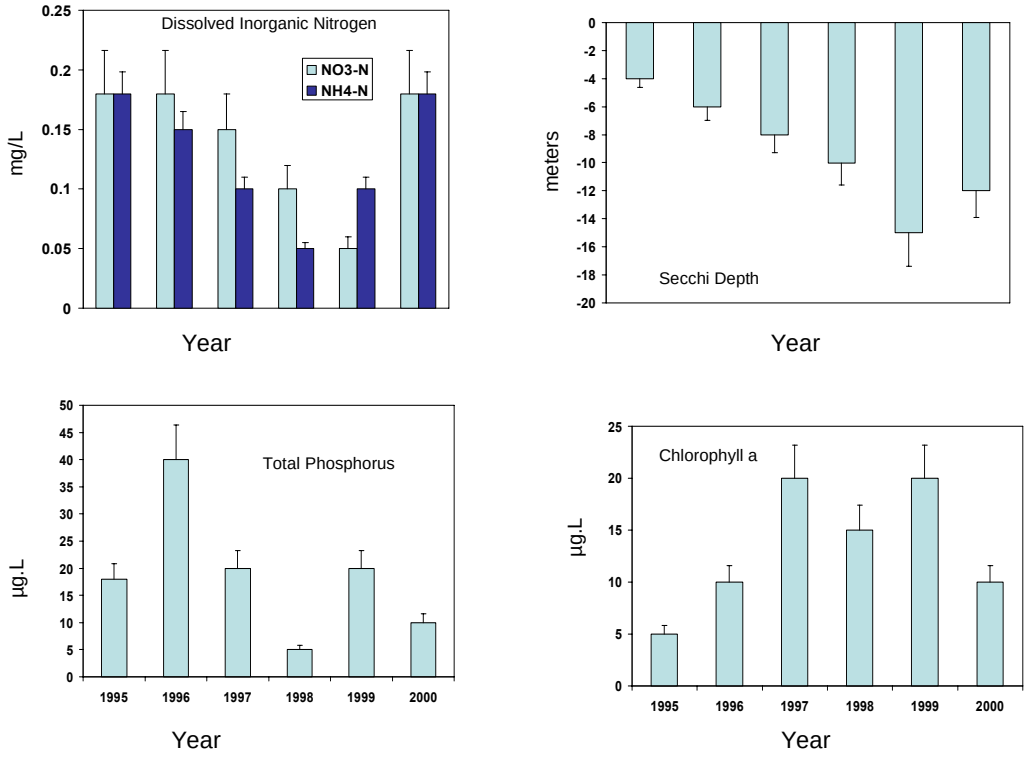


Figure 4. Example of bar chart displays for four water quality variables measured during 1995-2000 at a hypothetical lake. Error bars represent one standard deviation.

5.0 Personnel Requirements and Training

5.1 Roles and Responsibilities

The final staffing for the inland lakes monitoring project will depend, in part, on the development and approval of a formal staffing plan for the Network. We envision a water quality monitoring program for lakes and rivers conducted by two or more field crews overseen by a project manager (GLKN aquatic ecologist, GS/11) and assistant to the project manager (GLKN aquatic ecologist GS/9). The field crews will consist of a crew leader at the GS/6 or GS/7 level, and a crew member at the GS/4 or GS/5 level. Both positions will likely be seasonal, although permanent, subject to furlough positions are possible. Each crew of two will be stationed at one of the parks and will travel to other parks as needed to implement monitoring. The field crews will work on this water quality monitoring project for a limited number of pay periods per year, and may spend the remaining part of their time on other Network or park projects. The Network will explore the possibility of sharing seasonal positions with the parks. When a park has an aquatic person on staff, the Network will make use of such existing staff expertise on the crew when possible, paying for the time spent on I&M monitoring activities, and will provide the same training to the park person as to the rest of the crew members. The field crews will monitor water quality in both rivers and lakes; the responsibilities, training, and qualifications of the crew are the same for both protocols.

5.1.1 Project Manager

The role of the project manager is to serve as a liaison among other related water quality monitoring projects conducted by partners (e.g., state monitoring programs), park staff, other Network staff (field personnel, data manager), a contracted analytical laboratory, and other GLKN monitoring project managers. The individual will coordinate with resource management staff at the parks to ensure parks are informed of monitoring activities. Specific responsibilities of the project manager include the following:

- Coordinate field schedules and availability of supplies with field personnel
- Develop a training program for field personnel
- Develop, document, and oversee the implementation of standard procedures for field data collection and data handling
- Coordinate logistics with park staff
- Develop QA/QC measures for the project, supervise staff training, and conduct quality assurance checks of field sampling techniques at least once, mid-season, with each field crew
- Contract with an analytical laboratory for analysis of water samples, ensure lab results meet program needs (e.g., QA/QC procedures, meaningful minimum detection limits for dilute waters, adequate reproducibility of replicate samples)
- Supervise or perform data entry, verification, and validation
- Summarize data and analyze data, prepare reports
- Serve as the main point of contact concerning data content

The project manager will also work closely with the data manager in the following capacities:

- Complete project documentation in NPSTORET (describing who, what, where, when, why and how of a project)
- Develop data verification and validation measures for quality assurance
- Ensure staff are trained in the use of database software and quality assurance procedures
- Coordinate changes to the field data forms and the user interface for the project database
- Identify sensitive information that requires special consideration prior to distribution
- Manage the archival process to ensure regular archival of project documentation, original field data, databases, reports and summaries, and other products from the project
- Define how project data will be transformed from raw data into meaningful information and create data summary procedures to automate and standardize this process
- Establish meaningful liaisons with state counterparts to promote sharing of data on a timely basis

5.1.2 Assistant Project Manager

This person is largely responsible for implementing the monitoring protocol for water quality on large rivers, but will also have duties related to inland lakes. Specific responsibilities include:

- Assist with coordination of field schedules and supplies
- Assist with training field personnel
- Coordinate logistics with park staff
- Help ensure all aspects of QA/QC are met
- Perform data entry, verification, and validation
- Train other staff in the use of database software
- Assist with data analysis and report writing

5.1.3 Field Personnel (Field Crew Member/Leader)

The role of field personnel is to conduct all field work related to the monitoring project. Field personnel will include both a crew leader and a crew member. The crew leader is responsible for contacting the parks prior to each sampling event to ensure logistical requirements will be met. Responsibilities for both crew member and crew leader include the following:

- Complete all training for field sampling, sample handling, and boat operation, if required by park
- Complete all phases of field season preparation
- Collect data and samples according to developed protocols
- Pack and ship samples to analytical laboratory
- Maintain accurate field and office notes
- Ensure that all QA/QC procedures are implemented
- Maintain and calibrate equipment according to protocols and manufacturers' directions
- Communicate progress and accomplishments with the project manager during and after sampling at each park unit, and report any deviations from sampling protocols
- Download, enter, and verify data into databases as required

- Maintain documentation of important details of each field data collection period, including explanations of all deviations from standard procedures
- Maintain hard copies of data forms and send original data forms to archive on a regular basis
- Represent the Network in a professional manner, assist in maintaining positive communication among the Network, park staff, and the public

5.1.4 Data Manager

The data management aspect of the monitoring effort is the shared responsibility of the data collectors first, then the project manager, and finally the network data manager. Typically, field personnel are responsible for data collection, data entry, data verification, and validation. The data manager is responsible for data archiving, data security, dissemination, and database design. The data manager, in collaboration with the project manager, also develops data entry forms and other database features (as part of quality assurance) and automates report generation.

5.2 Crew Qualifications

The crew leader must have a bachelor's or advanced degree in biology, chemistry, or other related physical or biological science. Field experience is mandatory and laboratory experience is preferred. Prior leadership experience and good decision-making skills are highly desirable, as is experience with boats, motors, and canoes.

Crew members should have a background in biology, chemistry, or other related physical or biological science, although an undergraduate degree is not required. Prior field experience, including that with boats, motors, and canoes, is highly desirable and laboratory experience is preferred.

All crew members must be physically fit, able to work long hours in inclement weather, and able to carry heavy loads. Sampling at some parks will involve camping for several days at a time and portaging between lakes.

5.3 Training Procedures

Prior to data collection, field personnel must become familiar with the use, calibration, and maintenance of all meters and probes planned for use in the monitoring project. A combination of classroom and field training will be required prior to each field season. Personnel who were previously trained for this monitoring project will participate in a review of all methods and techniques. Specific details of the training procedures are covered in SOP #2 and will include:

- Basic limnological concepts and field sampling techniques
- Review of all SOPs for the project
- Calibration, operation, and maintenance of all field and laboratory meters and probes used in the project
- Methods for sample collection
- Methods for cleaning equipment
- Methods for handling and preserving samples

- Completion of field data forms, sample labels, chain of custody forms, analytical service request forms
- Data entry into NPSTORET
- Completion of field and calibration logbooks
- Use of GPS equipment
- Park-specific training requirements (e.g., boat operation, navigation, radios)
- NPS-specific training (e.g., computer use, credit card, travel)

6.0 Operational Requirements

6.1 Annual Workload and Field Schedule

The annual workload and schedule for the monitoring of water quality in inland lakes must be viewed within the context of the other planned water quality monitoring activities. We prepared the estimated workload and schedule for monitoring of inland lakes and large rivers together, but anticipate additional related protocols in the future (e.g., wadeable streams). As these additional protocols become part of the GLKN monitoring program, the workloads are likely to change.

Parks with inland lakes are APIS, INDU, ISRO, PIRO, SLBE, and VOYA. We will monitor water quality at each selected index lake three times during the open water season (May to October). The time it takes to conduct field work is always weather dependent, and this is especially true at parks where travel on Lake Superior or Lake Michigan is required (SLBE, ISRO, and APIS). Sampling can be delayed and field crews can be stranded for days when wind and waves prohibit boat travel. We estimate sampling to take from one day at INDU, to as much as 10 or more days at VOYA and ISRO, including travel time. Initial estimates of time required to sample at each park (explained in more detail, below, under staff salaries) assume minimal weather-related delays.

6.2 Facility and Equipment Needs

At each park, the field crew will need a facility with a sink and counter-top space where they can calibrate instruments, clean and store equipment, and process samples. They will also need a refrigerator and freezer for storing samples prior to shipment to an analytical laboratory, and secure space for storing a boat, motor and gasoline, canoe, and other field equipment. Availability of needed space varies across park units, but all park units with inland lake resources can meet the basic necessities with the exception of APIS, which does not have laboratory space. The Network office is located near APIS, however, and can provide the needed laboratory space.

6.3 Start-up Costs and Budget Considerations

6.3.1 Equipment

Each sampling crew will need its own equipment because sampling will occur at six parks each year (seven parks, including monitoring of large rivers), widely separated in distance. Some of the parks already have some of the necessary sampling gear and equipment and the Network has acquired supplies, as funds permit. When possible, we will coordinate with the parks in the use of their equipment. Sampling at APIS, ISRO, and the islands of SLBE requires large boats for travel on the Great Lakes. The Network has purchased two boats, with motors, trailers, and other necessary equipment, appropriate for use on Lake Superior at APIS and ISRO. The Network may be asked to help cover fuel costs and boat operator salaries when parks assist in transporting Network staff. Boats or canoes will be available to the Network initially at PIRO, INDU, and SLBE, though Network-owned crafts may be required in the future. The Network and VOYA together have purchased a boat, motor, and trailer to be shared by park and Network staff at that park.

Start-up costs are expected to be approximately $50,000 (Table 15), excluding the boats and accessories for use on Lake Superior; annual estimated costs of equipment and supplies are approximately $10,000. Both initial and annual costs include equipment and supplies that will be used by both the inland lakes and large rivers monitoring protocols. The large rivers monitoring project will require additional equipment, such as a flow meter, that is not needed for monitoring of inland lakes. Monitoring of inland lakes alone will cost approximately two thirds of the cost of the entire water quality program, or $33,000 in start-up costs and $7,000 for annual equipment and supplies.

Table 15. Expected costs of starting a water quality monitoring program for inland lakes and large rivers of the Great Lakes Network, including one-time purchases and routine expenses. '*' indicates start-up expenses; other expenses are expected to reoccur periodically or annually.

Item	Quantity	Cost Each	Total Cost
multi-probe sonde*	3	7000	21000
GPS unit and software*	3	500	1500
Secchi disk and non-stretch line*	4	130	520
digital camera*	4	400	1600
canoe and accessories*	2	1200	2400
boat, trailer*	1	8000	8000
benchmarks*	60	10	600
anchor*	3	50	150
integrated tube sampler*	10	20	200
Van Dorn*	4	300	1200
electric pump for filtering*	3	350	1050
benchtop pH meter*	3	400	1200
transparency tube*	3	55	165
refrigerator/freezer*	3	500	1500
laptop computer*	3	2500	7500
hand pump	5	125	625
certified thermometer*	4	30	120
Subtotal			$49,330
miscellaneous field equipment (boots, buckets, PFDs, backpacks)		2000	2000
replacement probes		400	400
miscellaneous lab equipment (glassware, forceps, acid, basins)		1500	1500
other consumables (calibration standards, filters)		2500	2500
shipping		3500	3500
Subtotal			$9,900
Total			$59,230

6.3.2 Staff Salaries

Field Crew: We estimated the field crew salaries based on the assumption that the positions would be seasonal GS/7 and GS/5. Exceptions may occur at some parks when an existing park staff person at a higher GS level conducts sampling. The Network expects to pay for the time park personnel spend on water quality monitoring.

The salary estimates include staff time for training, pre-season preparation, sampling, processing samples, packing and shipping samples, and data entry (Table 16).

Project Manager: The project manager's salary will be divided between I&M and WRD funding.

Aquatic Specialist: In 2007, the Network hired a permanent GS/9 subject-to-furlough ecologist to assist the project manager. This person is responsible for taking the lead in sampling for large rivers, but will also have responsibilities related to the inland lakes protocol. Salary for this position will be shared between I&M and WRD funding.

Data Manager: The data manager's salary will be covered entirely by the I&M program.

Table 16. Summary of the expected cost for personnel (salaries and benefits) for implementing the water quality monitoring protocol at inland lakes.

Position	Amount of Time	Cost
Project manager	50% WRD	$39,076
Aquatic specialist	25% WRD	$13,940
Crew leader GS/7	12 pay periods	$17,400
Crew members (3) GS/5	6 pay periods	$21,060
	Total	$91,476

6.3.3 Vehicle and Travel

We expect travel expenses to be approximately $7500 annually. This estimate includes GSA vehicles and travel (lodging and per diem), and is based on the following assumptions:
1) GSA vehicles will be shared with other monitoring projects or parks, when possible.
2) Park housing will be available at ISRO, VOYA, SLBE, and PIRO.
3) The crew leader will cover two or more parks and will travel between them.
4) Crew members will be stationed at parks and will work with the project manager, aquatic specialist, and crew leader, and will travel as needed.

6.3.4 Analytical Laboratory Costs

Monitoring guidelines established by WRD include strong recommendations for selecting an analytical laboratory that has been accredited by the federal National Environmental Laboratory Accreditation Program (NELAP) (2005a, b). The Network will assess the differences in detection and reporting limits among NELAP-approved, state accredited, and research laboratories, along with other criteria, prior to selecting a contract laboratory. The laboratory

selected by GLKN must be able to detect and report concentrations appropriately low such that changes in water quality variables can be detected early in the naturally dilute waters occurring throughout the Network. The laboratory selected must meet the detection limits outlined in SOP #12 and have a rigorous QA/QC plan.

For the purpose of estimating a budget for monitoring water quality of inland lakes, we use the costs quoted by the NELAP certified laboratory in Table 17. The estimates from the other laboratories are included as examples of what our costs might be if we selected one of them, instead.

Table 17. Estimates of laboratory costs for analysis of water quality parameters.

	White Water Assoc., GSA contract, NELAP certified lab	Natural Resources Research Institute	St. Croix Watershed Research Station	Central Michigan University
Alkalinity	$10	$12	$4	$6
DOC	$25	$18	$15	
Cl	$10	$23 (Cl w/ SO4)	$10	$5
SO4	$12		$10	$7
Na, K, Mg, Ca	$40	$23	NA	
TP	$12	$28 (dual TP and TN)	$20 (dual TP and TN)	$7
TN	$28 (as TKN)			
NH4-N	$12	$11	$15 (dual w/ NO3/NO2-N)	$1
NO3+NO2-N	$12	$12		$10.50
chlorophyll *a*	$40	$34	$10	$13
SiO2	$20		$10	
set-up fee	NA		$40	

We expect to measure nutrients (TP, TN, NO_3+NO_2-N, NH_4-N) and chlorophyll-*a* each sampling visit, or three times per survey-year, one near-bottom TP sample per year, and the remaining parameters once per survey-year (three times during the first sampling year, though estimated

costs are calculated based on once annually). Annual estimated laboratory analysis costs range from a low of $441 at INDU to a high of $3,969 at ISRO (Table 18).

6.3.5 Total Estimated Annual Costs and Start-up Costs

Estimates for starting a long-term water quality monitoring program ($49,330) and the annual implementation costs ($123,500; Table 19), at the six parks with inland lake resources are high – more than the Network receives from WRD ($120,100). Monitoring water quality of large rivers (Magdelene et al. 2007) and wadeable streams (protocol in preparation) are not included in these estimates, putting the total cost of monitoring water quality well beyond the funding WRD provides. Because of the importance of water quality to GLKN parks, the Network is contributing substantial I&M funds to implement these water quality monitoring protocols.

Table 18. Estimated costs of laboratory analyses by park.

Analytes →	4x/yr (TP)	3x/yr (chlorophyll-*a*, nitrogen species)	1x/yr (alkalinity, ions, DOC, SiO2)	Total
Cost per site	$48	$276	$117	$441
APIS	$192	$1,104	$ 468	$1,764
INDU	$ 48	$ 276	$ 117	$ 441
ISRO	$432	$2,484	$1,053	$3,969
PIRO	$240	$1,380	$ 585	$2,205
SLBE	$288	$1,656	$ 702	$2,646
VOYA	$384	$2,208	$ 936	$3,528
Duplicates (10%)				$1,455
Equipment blanks				$1,475
Total				$17,483

Table 19. Total estimated annual costs for monitoring water quality at GLKN inland lakes.

Item	Cost
Equipment for start-up (not included in total)	$33,000
Annual equipment and supplies	$7,000
Salary and benefits	$91,500
Travel	$7,500
Laboratory analyses	$17,500
Total	$123,500

6.4 Procedures for Revising and Archiving Previous Versions of the Protocol

As our water quality monitoring program matures, revisions to both the protocol narrative and specific standard operating procedures (SOPs) are likely. Documenting changes and archiving copies of previous versions of the protocol and SOPs are essential for maintaining consistency in

the collection of data and for appropriate interpretation of the data summaries and analyses. The NPSTORET database contains a field for each monitoring component that identifies which version of the protocol was being used when the data were collected.

The rationale for dividing a sampling protocol into a protocol narrative with supporting SOPs is based on the following:

- The protocol narrative is a general overview of the protocol that gives the history and justification for doing the work and an overview of the sampling methods, but does not provide all methodological details. The protocol narrative will only be revised if major changes are made to the protocol.
- The SOPs are specific step-by-step instructions for performing a given task. They are expected to be revised more frequently than the protocol narrative.
- Usually, when a SOP is revised, it is not necessary to revise the protocol narrative to reflect the specific changes made to the SOP.

All versions of the protocol narrative and SOPs will be archived.

The steps for changing the protocol (either the protocol narrative or the SOPs) are outlined in Procedures for Revising the Protocol, SOP #13. Each SOP contains a Revision History Log that must be updated each time a SOP is revised, to explain why the change was made and to assign a new version number to the revised SOP. The new version of the SOP or protocol narrative should then be archived in the appropriate folder of the GLKN database structure.

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Standard Operating Procedures

SOP #1: Pre-season Preparation
SOP #2: Training and Safety
SOP #3: Using the GPS
SOP #4: Measuring Water Level
SOP #5: Decontamination of Equipment to Remove Exotic Species
SOP #6: Field Measurements and Water Sample Collection
SOP #7: Processing Water Samples and Analytical Laboratory Requirements
SOP #8: Data Entry and Management
SOP #9: Data Analysis
SOP #10: Reporting
SOP #11: Post- Season Procedures
SOP #12: Quality Assurance/Quality Control
SOP #13: Procedure for Revising the Protocol

Standard Operating Procedure #1: Pre-Season Preparation

Version 1.0

In **Water Quality Monitoring Protocol for Inland Lakes**

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Revision History Log

The following table lists all edits and amendments to this document since the original publication date. Information entered in the log must be complete and concise. Users of this standard operating procedure will promptly notify the project manager and/or the Great Lakes Network (GLKN) data manager about recommended and required changes. The project manager must review and incorporate all changes, complete the revision history log, and change the date and version number on the title page and in the header of the document file. For complete instructions, please refer to Revising the Protocol, SOP #13.

Revision History Log:

Previous Version #	Revision Date	Author (with title and affiliation)	Location in Document and Concise Description of Revision	Reason for Change	New Version #
Add rows as needed for each change or set of changes tied to an updated version number					

Acknowledgements

We relied upon documents by O'Ney (2005) and the U.S. Geological Service (USGS 2005) for guidance in writing this standard operating procedure.

1.0 Introduction

Prior to the field season, many preparations must be completed to ensure sampling can be undertaken according to schedule. The field season for sampling inland lakes of the Great Lakes Network parks is generally from May through October. All details for the season need to be planned well in advance. Field preparations should begin in January to allow enough time for ordering new supplies and equipment, if necessary. Table 1 provides a checklist and general guidance for activities conducted prior to sampling. Many of these activities are discussed in more detail in other SOPs.

Table 1. Checklist of activities to be conducted prior to sampling inland lakes.

√	Activity	Description
	Prepare calendar of planned field trips	Includes sampling dates, locations, personnel
	Review sampling methods to determine if revision is needed	Check web reference to see if method has been updated from version currently used
	Review checklists of equipment and supplies required; prepare list of items to be ordered	Check each Standard Operating Procedure for detailed equipment lists; check expiration dates of reagents, standards, and other chemicals
	Order supplies	Includes calibration standards, pre-cleaned bottles for sample collection (if not provided by the contract analytical laboratory) , sample preservation solutions
	Clean and test equipment; charge or replace batteries as needed	Includes multiparameter sonde, integrated sampling tube, Van Dorn, back-up instruments, ropes, thermometers, camera, GPS unit, cell phone or radio
	Ensure the latest versions of software are being used	Includes mulitparameter sonde, data-logger, computer
	Prepare equipment blanks	Must be done annually
	Obtain permission for site access, if necessary	
	Confirm current park research and collection permits	
	Check field vehicle and boat for safety equipment and supplies	Includes material safety data sheets, flares, flashlight, gloves, extra sampling bottles, etc.
	Schedule boat training, if necessary	
	Update field folder	Include maps, site information, field forms, sampling procedures
	Prepare headers on field data forms, chain of custody forms, analytical service request forms, bottle labels	Header information should be cross-checked with metadata to permit entry into NPSTORET
	Review sample collection, processing, and documentation information	Includes methods, lab codes, bottle type, and sample collection and processing procedures; sample shipment; quality control samples. (SOPs #6 and #7)
	Make travel reservations and arrangements as needed	
	Provide supervisor with schedule	

1.1 Read the Entire Protocol

Periodically read through the entire protocol, including all standard operating procedures (SOPs). Be sure to understand the purpose for which the various types of data will be collected and review the SOPs for the types of measurements and samples needed. Be alert for portions of the protocol or SOPs that may be in need of revision, and bring these sections to the attention of the appropriate supervisor.

1.2 Prepare Calendar of Planned Field Sampling

Well in advance of the field season, prepare a calendar of sampling dates for the entire season. Allow for the possibility of bad weather days, when sampling may have to be postponed. Include the location of sampling, dates, parameters to be measured, personnel, and any additional relevant notes (Table 2).

Table 2. Example of calendar of planned field sampling.

Location	Sampling Dates	WQ Variables	Personnel	Notes
Indiana Dunes	May 1-5	core suite, chl *a*, TP, TN, NO2+NO3-N, NH4-N, alk, cations, anions, DOC	VanderMeulen, park biotech	
Indiana Dunes	July 15-20	core suite, chl *a*, TP, TN, NO2+NO3-N, NH4-N	VanderMeulen, park biotech	collect bottom water sample for analysis of same parameters if lakes are stratified
Indiana Dunes	Oct. 15-20	core suite, chl *a*, TP, TN, NO2+NO3-N, NH4-N, alk, cations, anions, DOC	VanderMeulen, park biotech	
Voyageurs	May 10-25	core suite, chl *a*, TP, TN, NO2+NO3-N, NH4-N, alk, cations, anions, DOC	Elias, park biotech	
Voyageurs	July20-Aug 5	core suite, chl *a*, TP, TN, NO2+NO3-N, NH4-N	Elias, park biotech	collect bottom water sample for analysis of same parameters if lakes are stratified
Voyageurs	Oct. 1-15	core suite, chl *a*, TP, TN, NO2+NO3-N, NH4-N, alk, cations, anions, DOC	Elias, park biotech	

1.3 Review Checklists of Equipment and Supplies

Checklists help ensure that equipment and supplies will be ordered on time, data collection activities will be completed appropriately, and data quality objectives will be met. Review the detailed equipment lists that are included with each standard operating procedure (Table 3). Pay attention to expiration dates on reagents, calibration standards, and all other chemicals. Prepare a list of equipment and supplies that must be ordered and present it to the project manager.

Table 3. Checklists of equipment and supplies for monitoring water quality of inland lakes.

Checklist	Location
Safety equipment checklist	SOP #2
Decontamination equipment and supplies	SOP #5
Field supplies and equipment checklist	SOP #6
Laboratory equipment and supplies	SOP #7

1.4 Confirm/Apply/Renew Research and Collecting Permits

For sampling stations located within park boundaries, a Research and Collecting Permit must be obtained before any work can be done. To renew or apply for the permit, go to the following website:
http://science.nature.nps.gov/research/ac/apps/appInstructions

Follow the directions for renewing an existing permit, or if your project is not already in the system, then follow the directions to apply for a new permit. Work with the research coordinator at each park.

1.5 Review Sample Collection, Processing, and Documentation

Conduct a thorough review of "Field Measurements and Water Sample Collection" (SOP #6) and "Processing Water Samples and Analytical Laboratory Requirements" (SOP #7).

Check with the project leader to determine current contract analytical laboratory information. Contact the laboratory to verify lab codes and procedures. Obtain copies of Analytical Services Request (ASR) and Chain of Custody (COC) Forms.

1.6 Update Field and Office Binders

Field binders should contain reference information specific to each sampling station, including maps, photos, previous data, field forms, and summaries of sampling and QA/QC procedures. The office binder should contain reference information relevant to general field sampling

procedures, including quality assurance/quality control (QA/QC) reminders, copies of all SOPs relating to safety, decontamination, sample collection and processing, copies of equipment instructions and troubleshooting, calibration logs, Material Safety Data Sheets (MSDSs), and ASR and COC forms. The field binder should be taken along on each sampling trip.

Each year, prior to the sampling season, the field binder for each monitoring site should be reviewed and the following information updated as needed:

- *Location of lake level gage or benchmark (if one is present).*
- *Location of sample-collection sites.* Review field notes for any indication that the location for sample collection may need revision. Update protocol if necessary.
- *Name of landowner, tenant, or other responsible party.* If the sampling station is located on private land, ownership may change. Verify.
- *Current copy of research and collection permit (if site located within NPS boundaries).* Check dates on permit. Renew/apply as described above.
- *Site access instructions (for example, call owner or site operator before arrival at site, obtain key to unlock security gate).* Confirm contact person, procedure, and phone numbers.
- *Photographs to document site conditions*. Take new digital photograph annually.
- *Maps to site (state and local).* Review map for accuracy; update if necessary.
- *Review previously collected chemical, physical, and biological data.* A summary of previously-collected data or copies of previous field data sheets should be in the field folder so that water column profiles and Secchi data can be compared to previous surveys. Familiarity with previously collected data is a critical quality assurance (QA) element for early detection of possible instrument malfunction.
- *Summaries of field procedures, QA/QC procedures, instrument stabilization criteria, etc.* Prepare brief outlines reminding field personnel of routine procedures, including all changes from the previous year.

Each year, prior to the sampling season, the office binder should be reviewed and the following information updated as needed:

- *Safety information (SOP #2).* Verify/update "Medical Information Form for Field Personnel" and "Emergency Contact Form".
- *Sampling schedule and instructions.* Ensure the following information from SOP #6 (Field Measurements and Water Sample Collection) is included in the office binder: laboratory analyses to be requested and associated codes, when to collect samples, bottle

types needed for each analytical schedule, preservation requirements, quality control sample requirements, and shipping instructions. Verify information is correct and report and reconcile any discrepancies to supervisor.

- *Decontamination procedures (SOP #5).* Ensure that the most recent information on presence of exotic species and need for decontamination of equipment has been incorporated into the Hazard Analysis and Critical Control Plan (HACCP) for each park. Update office binder with the latest information. If the order of lakes to be sampled must change due to new infestations, be sure sampling schedule is updated.

- *Analytical service request forms, data collection field forms, chain of custody forms, sample bottle labels*. Prepare as much of the field forms as possible in advance. For each station, complete the header information, including the project ID, station ID and station name and other required metadata for NPSTORET. Place enough blank field forms in office folder to last entire field season.

- *Ensure that copies of the current field procedures are included in the office folder.* Include calibration and maintenance procedures specific to the instruments to be used.

1.7 Clean and Test Equipment

Clean and test all sampling equipment, including multiparameter sonde, Van Dorn and integrated tube samplers, camera, GPS units, and any back-up meters. Check calibration of metered ropes to ensure accurate depth measures. Start each new field season with fresh batteries and replace spares in field tool kit. Ensure the latest versions of software are loaded onto the multi-probe, data-logger, and computer.

1.8 Vehicle, Boat, and Safety Gear

Check maintenance schedule of field vehicle and arrange maintenance, if needed. Check boats and vehicle for safety equipment such as MSDS sheets, flares, spare tire, triangles, cones, first aid kit. Prepare a list of supplies needed and present list to supervisor. If using a trailer, ensure that tail-lights are in working order. Check that field tool-kit is complete and replace tools, as needed.

1.9 Training and Safety

Keep current with training and the laboratory requirements associated with your data collection activities. New technicians will need basic skills training, including classroom instruction, hands-on training, and pilot-testing of equipment. Continuing field staff should attend annual refresher training. If boat training is needed, be sure to schedule the training with the park early in the season. Initial and periodic refresher courses in basic first aid and CPR are required.

1.10 Field Reconnaissance

Make field reconnaissance trips, if possible. Visit the sampling sites to be sure that conditions have not changed from the previous year. Note conditions that could affect sampling operations, such as the seasonal high or low water levels, or site access peculiarities. In parks where lakes are accessible via roads, ensure all roads are passable and landing areas are accessible. In cases where lakes are not accessible via roads, communicate with park backcountry staff to learn of potential trail closings or other hindrances to sampling. When boats or canoes will be kept at certain lakes for the season, work with park staff to get the boats/canoes on site, hidden (if necessary), and secure.

1.11 Travel Arrangements

Make travel arrangements. Because hotel and campground reservations may be difficult to impossible to obtain at certain times of year, it is important to review the sampling schedule and plan ahead. Submit park housing requests well in advance of the sampling season.

1.12 Communicate with Supervisor

Ensure the project manager is informed of supply needs, problems with instruments, changes in sampling schedule, changes in sampling site conditions, and other needs that may have an impact on the project budget, data collection, schedule, or sampling design.

1.13 Equipment Blanks

An equipment blank should be conducted annually at each park where sampling is scheduled, at least four weeks prior to using the equipment in the field to ensure adequate time for analysis and review of results. Equipment blanks should be collected in a designated clean area of the sample processing laboratory. The blank consists of deionized water that is passed sequentially through each component of the sample collection and processing equipment. Equipment blanks should also be conducted when a new cleaning procedure is instituted and when new equipment will be used for the first time.

Procedure

- Fill the integrated sampling tube or Van Dorn with deionized water (DIW).
- Dispense water from integrating tube or Van Dorn into cubitainer or carboy.
- From cubitainer or carboy, dispense water directly into appropriate analyte bottles, or filter first, according to instructions for each analyte (SOP #7).
- Preserve samples according to instructions for each analyte in SOP #7.

If the equipment-blank data indicate that the equipment does not introduce contaminants that will bias study results, sampling can proceed. If the equipment-blank data indicate unacceptable

concentrations of analytes of interest, the cause must be identified and the equipment or cleaning procedures must be changed or modified before sampling can proceed.

1.14 Literature Cited

O'Ney, S.E. 2005. Standard operating procedure #2: Pre-season activities, Version 1.0. *in* Regulatory water quality monitoring protocol, Version 1.0, Appendix E. Bozeman (MT): National Park Service, Greater Yellowstone Network.

USGS. 2005. National field manual for the collection of water-quality data: U.S. Geological Survey Techniques for Water-Resources Investigations, book 9, chaps. A1-A9.

Standard Operating Procedure #2: Training and Safety

Version 1.0

In **Water Quality Monitoring Protocol for Inland Lakes**

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Revision History Log

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Add rows as needed for each change or set of changes tied to an updated version number					

Acknowledgements

The safety related portions of this standard operating procedure were adapted from the Greater Yellowstone Network's SOP on safety (O'Ney 2005), with heavy reliance on the U.S. Geological Survey's manual for collecting water quality data (Lane and Fay 1997).

2.0 Introduction

Prior to collecting data and water samples in the field, the field crew members must be trained in the techniques and procedures that will be used throughout the season. Familiarity with the protocol and standard operating procedures (SOPs), as well as with boats, equipment, and basic safety standards, are critical to the success of the water quality monitoring program. This SOP includes procedures for training in the specific water quality related skills and knowledge necessary for collecting good data and understanding those data. The crew must be also trained in specific safety procedures to ensure their safety and that of others.

The project manager will conduct or arrange for all training needed prior to the field season.

2.1 Pre-Season Classroom Training

It is desirable to begin training well before the field season begins to allow adequate time for thorough understanding of field and laboratory procedures and to obtain certification in boat use. Field crew leaders must undergo all of the following training. Training in boat use is highly recommended for other field crew members, and training in the remaining areas is desirable.

2.1.1 Limnological Concepts

An understanding of basic limnological concepts is useful for recognizing bad or illogical data in the field. For example, a dissolved oxygen reading of 30 mg/L may indicate a malfunction of the multiparameter sensor, or something as simple as fouling of the probe. Recognition of the problem at the time it occurs allows for immediate adjustment in the field, for example cleaning the membrane on the probe or changing the batteries, so that good data can still be collected.

The field crew leaders, and if possible, other crew members, will study select modules of the Water on the Web (2004) curricula (http://waterontheweb.org/curricula). The modules will be selected by the project manager and will include those on lake surveys (e.g., field profiles, sample collection, laboratory methods). Individual study will be followed with group discussion and/or individual discussion with the project manager or a limnologist.

2.1.2 Understanding the Protocol and Standard Operating Procedures

Reading and understanding the entire protocol and all SOPs are crucial prior to initiating field work. The project manager will allow adequate time for all field crew members to complete this step to ensure success of the project. Field and laboratory related SOPs will also be covered as part of the hands-on training, described below.

2.1.3 First Aid and Cardio-Pulmonary Resuscitation (CPR)

Training in the basic medic/first aid and Heartsaver AED, which includes CPR and use of an automated external defribrillator (AED), is required for all crew members and will be paid for by the Network. Acceptable training should be through the American Red Cross or American Heart

Association. Certification is valid for two years. Training and certification should be acquired prior to the field season.

2.2 Hands-On Training

In addition to the classroom training described above, a variety of hands-on training and practice prior to the first sampling period will help ensure high quality data collection. Familiarity with the use and maintenance of equipment, procedures for collecting and processing water samples, techniques for cleaning field and laboratory equipment, and safe use of watercraft are essential to the success of the water quality monitoring project. Field crew leaders are required to complete all of the following training; other field crew members should also complete the training, if possible, although it is not required.

2.2.1 Use of a Multisensor Water Quality Instrument

Each type of multisensor instrument comes with specific instructions on use and care. Guidelines for calibration and use of multisensor instruments are included in SOP #6, however it is important to use the instruction manual specific to each instrument. Check the manufacturers' websites for updates or changes to instructions.

Training in the use of a multisensor instrument will include the following:

- calibration procedures and acceptance criteria
- keeping a calibration log
- maintenance, including replacing fluids and membranes
- creating files on the data logger
- storing data on the data logger
- downloading data to a laptop computer
- use of the instrument in a field setting, including depth profiles and equilibration
- troubleshooting

Crew members will have the opportunity to practice the skills learned prior to the actual sampling until they are comfortable with the use of the instrument.

2.2.2 Use of a Global Positioning System (GPS)

Location information must be gathered via GPS for each site during each visit. Training in the use of a GPS will include navigation to a known location, acquiring location information, storing data, and downloading data. Details on the use of a GPS can be found in SOP #3.

2.2.3 Field Methods

In addition to collecting data with the multisensor instrument, a field data sheet must be completed, a water sample must be collected, and the water level must be determined at each site. Prior to the field season, the field crew will receive training in and have the opportunity to practice the following:

- completing the field data sheet
- using an integrated sampling tube
- using a Van Dorn sampler
- reading a staff gage
- decontaminating equipment between lakes to avoid transfer of species from one lake to another, and determining when decontamination is necessary
- following QA/QC procedures

2.2.4 Processing Water Samples

Whether the water samples are processed for further analytical laboratory analysis in the field or back at the office or lab, strict procedures must be adhered to (see SOP #7). Crew members will be trained in, and will have the opportunity to practice the following techniques:

- handling water samples so as to avoid contamination
- rinsing and filling bottles from the analytical laboratory
- preserving samples for various chemical analyses
- filtering samples for various analyses
- packing samples for shipment to analytical laboratory
- filling out chain of custody forms
- following QA/QC procedures

2.2.5 Cleaning Field and Laboratory Equipment

Field and laboratory equipment must be cleaned between lakes or samples to avoid contamination with water from the previous sampling site. Training in proper techniques will include:

- cleaning equipment with P-free detergent
- setting up an acid bath
- cleaning equipment with an acid bath
- rinsing with distilled or de-ionized water

2.2.6 Boat Training

Prior to operating a NPS boat or canoe, training and certification are required. The crew leader must receive the training and obtain certification, and it is highly desirable for the remaining crew members to do so as well. The project manager will arrange for training prior to the field season through one of the several GLKN parks that offer it. Arrangements should be made well in advance of the field season.

2.3 Safety Procedures

Safety of field personnel should always be the first concern in conducting a sampling program and in the selection of sampling sites. Numerous safety issues and concerns are associated with implementing a water quality monitoring program that includes extensive field work and sampling. Field personnel routinely come into direct and indirect contact with waterborne pathogens, chemicals, and potentially hazardous plants and animals. Field work requires an awareness of potential hazards and knowledge of basic safety procedures. Advanced planning can reduce or eliminate many safety hazards.

2.3.1 USGS Field Manual

This SOP is meant to be used in conjunction with Chapter A9 of the USGS National Field Manual (Lane and Fay 1997), which contains more complete information about potential hazards that water quality monitoring field personnel may encounter during field work and the procedures that, when implemented properly, will help ensure the safety and health of field crew members. A copy of this manual is provided to the field crew and may be downloaded from http://water.usgs.gov/owq/FieldManual/Chap9/content.html. Topics addressed in the USGS document include:

- general references for federal policies and Department of Interior (DOI) safety guidelines
- safety policies you are required to know and follow under the Occupational Safety and Health Act (OSHA), Environmental Protection Agency (EPA), and Department of Transportation (DOT);
- understanding and implementing a job hazard analysis (JHA);
- requirements related to use of personal protective equipment (PPE) on the job
- safety training and certification requirements; safety issues associated with transportation and operation of vehicles (road vehicles and trailers, watercraft, aircraft etc.) used to reach sampling sites
- surface water activities (e.g., wading, working from bridges, boats and cableways, etc.)
- working around machinery, pumps, and other equipment
- proper use, handling, transport, storage, and disposal of chemicals
- handling of contaminated water and limiting exposure to yourself and others
- environmental conditions caused by extremes in temperature; sun exposure; threats posed by storms, floods, fire, snow, ice, and various animals and plants

In addition to consulting the USGS manual, the field crew should contact individual park's safety officers or resource managers for information on park radio safety procedures and local problems and issues, such as dangerous or nuisance animals (e.g., black bears at VOYA, red fox at ISRO), insect-and tick-borne diseases (e.g., Lyme disease, encephalitis, West Nile disease), and other issues specific to each park.

2.3.2 Basic Safety Preparation

Basic preparations should become routine before every sampling activity. At a minimum, complete a trip plan for each field trip, and leave it at a designated location in the office. The trip plan should include the following information:

- field trip participants, including guests and observers, with emergency contact information
- departure and expected return time(s) and date(s)
- hotel and campground contact information (for overnight trips)
- basic itinerary, including where and when sampling will occur
- phone numbers for cellular phones or radio frequencies

Field work should be done in pairs. Always carry a park radio or a cellular telephone. Carry basic safety equipment, including first aid kit, flashlight, boots, rain gear, antibacterial soap or hand cleaner, matches or lighter, etc. Be aware of changing weather conditions and the potential for storms. Be aware of potential hazards at a monitoring site. Carry general safety information in each vehicle or boat, including:

- material safety data sheets (MSDS) for preservatives
- basic first aid protocols
- emergency phone numbers
- locations of emergency facilities (hospitals, police and fire departments, U.S. Coast Guard)
- maps of the park, surrounding area, and nearest city

Job hazard analyses (JHAs), prepared by the aquatic ecologist, will be discussed with field personnel prior to the field season. The JHAs will cover such topics as hiking and portaging, boating and sampling from a boat/canoe, lab safety, driving vehicles, and stinging insects and poisonous plants.

2.3.3 Medical Forms and Safety Equipment Checklists

The following pages contain medical forms and equipment checklists for field personnel (adapted from Lane and Fay 1997). Prior to the field season, complete as much of the medical information as possible. Confirm all contact information annually. Medical information sheets should be completed for each individual venturing into the field.

Checklists are helpful for ensuring that personnel have the appropriate safety equipment available during field trips. Field crew members should consider their specific needs and should customize the checklists as necessary. The field crew and project manager will discuss the checklists and determine which items are necessary.

Emergency Contact Form for: (name)_____

Emergency contacts

#1 Name: _____Relationship:_____

Phone: (home) (work)_____

#2 Name: _____Relationship:_____

Phone: (home) (work)_____

Great Lakes Network Contacts

Network Office 715-682-0631 x25 Mississippi NRRA _____

Apostle Islands NL _____ Pictured Rocks NL _____

Grand Portage NM _____ St. Croix NSR_____

Indiana Dunes NL_____ Sleeping Bear Dunes NL _____

Isle Royale NP _____ Voyageurs NP_____

Local emergency contacts (or call 911)

Hospital Phone: _____

Address: _____

Other medical facility (24-hour care) Phone:_____

Address:_____

Police_____

Fire_____

Utility_____

Health Information Centers

Center for Disease Control_____

Information Hotline: _____

Other_____

Medical Information Form (retain in office)

Employee name: _____ Home phone: _____

Treatment preference: medical _____ other (specify) _____

Doctor: _____ Phone: _____

Other emergency contact: _____ Phone:_____

Allergies and other medical conditions	Medications being taken	Medications to avoid

Relevant medical history:

Special instructions:

General Safety Equipment Checklist

√	**Basic Safety Equipment Checklist**
	Waders, hip boots, rubber knee boots
	Personal floatation device (PFD)
	First aid kit
	Fire extinguisher
	Flashlight and spare batteries
	Park radio and cellular phone
	Rain gear
	Hat, sun screen, and sunglasses
	Drinking water or sports drinks
	Safety cones, orange safety vest (working on bridges)
	Tool box with basic tools
	Antibacterial soap or hand cleaner
	Spill kits (for preservatives)
	Material safety data sheets (MSDS) for preservatives
	Hand-held eye wash unit
	Protective goggles
	Container to carry preservatives
	List of emergency phone numbers and office contacts

Personal Protective Equipment Checklists

Personal Protective Equipment (PPE) must be selected based on the hazards likely to be encountered. The Great Lakes Network is required to supply appropriate PPE, and field personnel are required to use it.

√	**Chemical and disease protection**
	Aprons
	Eye/Face splash guards
	Gloves (vinyl and/or latex or nitrile)
	Protective suits
	Respirators (certification required for use)

√	**Weather and UV protection**
	Boots
	Fluids (e.g., water, sports drinks)
	Hat with a brim
	Insect repellent
	Rain gear
	Sunglasses
	Sunscreen
	Temperature-modifying clothing
	Work gloves

√	**Flotation and reflective protection**
	Orange flotation vests and jackets
	Safety harness

√	**Protection for working around boat motors**
	Hearing protection

Checklists for Vehicles and Vehicular Laboratories

√	**Chemical protection and storage**
	Chemical spill kit
	Eye wash kit (replace old or expired wash solution)
	Material Safety Data Sheets (MSDS)
	Chemical reagents (stored in appropriate area)
	Flammable solvents (stored in appropriate dedicated area)
	Pressurized gases (stored in appropriate area)

√	**Communications and instructions**
	Field folder (including maps, emergency phone numbers for medical facilities, office contacts, family contacts)
	Cellular phone/communication equipment (check that the service is operational for the area to be traveled)

√	**First aid and protective equipment**
	Complete change of clothes (stored in dry area)
	Fire extinguisher (safely secured)
	First aid kit and manual (check for missing or old, expired items and replace if necessary)
	Orange reflective vest

√	**Miscellaneous equipment**
	Bungie cords (to secure loose articles)
	District flood plan (most current version)
	Flagging
	Duct tape
	Knife or multi-tool
	Flares
	Flashlight (including fresh batteries)
	Flexible hose (to vent exhaust away from vehicle)
	Safety cones
	Tool kit
	U.S. Geological Survey TWRI Book 9 Chapter A9.

Watercraft Checklists

√	**Instructions and navigation**
	Field folder, with sampling plans
	Charts and maps
	Compass
	Depth finder
	Dead-man's switch
	Navigation lights
	Ring buoy with line

√	**Distress and external communication**
	Radio (VHF, AM, FM, and WEATHER)
	Special lighting/flagging (if boat activities might pose a hazard to the public, such as tag line measurements)
	Visual distress signals (Coast Guard approved)
	Whistles or horns
	Type IV throwable rescue device
	Personal flotation devices for each passenger (Coast Guard approved)
	Anchor and lines (spare)
	Bucket for use as a bailer (sponge for use in canoes)
	Paddle (extra paddle for each canoe or rowboat)
	First aid kit (Coast Guard approved)
	Flashlights and batteries
	Fire extinguishers
	Spare parts (anchor, fuel, propeller, extra lines, cotter pin)
	Tool and repair kits
	Extra clothes (hat, foul-weather gear)
	Food and water
	Sunscreen
	Conversion factors and abbreviations

2.4 Literature Cited

Lane, S.L., and R.G. Fay. 1997. Ch A9: Safety in field activities. *in* National field manual for the collection of water-quality data: U.S. Geological Survey techniques of water-resources investigations, Book 9. Available from: <http://pubs.water.usgs.gov/twri9A9/>.

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Water on the Web (WOW). 2004. Monitoring Minnesota lakes on the internet and training water science technicians for the future - A national on-line curriculum using advanced technologies and real-time data. University of Minnesota-Duluth, Duluth, Minnesota. (http://waterontheweb.org/curricula)

Standard Operating Procedure #3: Using a GPS

Version 1.0

In **Water Quality Monitoring Protocol for Inland Lakes**

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Acknowledgements

Major portions of this SOP have been adopted from the GLKN GPS Field Data Collection Guide. The guide was originally published as Appendix K to the Great Lakes Inventory and Monitoring Data Management Plan (Hart and Gafvert 2005). Appendix A of this SOP was also adopted from that document, and contains a summary discussion of the general types of GPS units available, as well as definitions of terms commonly associated with use of GPS units.

3.0 Introduction

This Standard Operating Procedure (SOP) provides guidance on some of the more common operations associated with global positioning system (GPS) units. Although most GPS units are capable of multiple functions, only those operations relevant to the protocol established to monitor water quality on inland lakes (Elias et al. 2007) are discussed.

GPS units currently (2007) used by water quality monitoring staff are the Trimble GeoXT and Garmin 76S. The Trimble GeoXT is an example of a mapping-grade GPS unit, while the Garmin 76S is an example of a recreational-grade unit. Mapping-grade units record data with location accuracy ranging from sub-meter to less than five meters. Recreational-grade units generally are not as accurate, with spatial accuracy less than 15 meters. Mapping-grade units have greater ability to capture spatially referenced metadata (i.e., attributes) than recreational-grade GPS. A detailed discussion of these types of GPS can be found in Appendix A.

As of 2007, software pertinent to the use of these GPS units includes:

- TerraSync (Trimble GeoXT) – single table forms software
- ESRI ArcPad – multi-table mobile GIS/database software
- GPS Pathfinder Office 4.xx (Trimble GeoXT) – desktop GPS processing software
- ESRI ArcGIS 9.x (Trimble GeoXT or Garmin 76S) – desktop GIS software
- Minnesota Department of Natural Resources Garmin Extension for ArcView (Garmin 76S) (i.e., DNR_Garmin)
- NPSTORET software, Version 1.xx – NPS database for water quality data (refer to SOP #8, Data Entry and Management).

Due to the rapid development of commercial software and hardware capabilities, it is likely that other GPS units or software will be utilized in the future. Therefore, this SOP is meant to act as a working document that is updated periodically as new hard-software becomes available. Although nomenclature may differ depending on what hard-software is utilized, this document should provide sufficient guidance on the general process of data collection using GPS tools until the SOP is revised. It is strongly recommended that water quality monitoring staff obtain unit-specific GPS training prior to deploying in the field. The training should include hands-on use, and should be designed to test all appropriate functions and operations prior to going out into the field.

Additionally, this SOP is not intended to be exhaustive or simply a regurgitation of operating manuals, but a document that might be carried into the field or periodically reviewed by field technicians and project leaders. Although some of the information in this SOP is specific to the water quality monitoring effort by GLKN, much of the text contained herein is applicable to other data collection efforts by GLKN staff. The objective of this document is to summarize GPS use guidelines applicable to the water quality monitoring efforts for inland lakes at GLKN partner parks.

3.1 Role of GPS in Water Quality Monitoring on Inland Lakes

GPS units are primarily used in the following ways to support water quality monitoring on inland lakes:

1) Permanent markers on the shore are installed in order to measure water level relative to the marker. GPS units are used to record the location of each marker and the bearing and distance between the marker and a known landmark (e.g., fire-ring at a campsite). A detailed discussion of how reference markers are installed and water level is measured is found in SOP #4, Measuring Water Level. It is recommended that a mapping-grade GPS unit be used to obtain a higher precision location during installation of reference markers. These coordinates, along with detailed descriptions, should be used relocate the marker.

2) For water quality monitoring on inland lakes, navigating to and sampling at the position locations of monitoring stations is accomplished through a combination of:
    - Using GPS units to navigate to previously established GPS point locations
    - Using hardcopy topographic maps and written notes with site descriptions
    - Using a depth sounder to verify site is at the deepest location
    - Comparing digital photos taken during site establishment with observer ocular estimates
    - Field experience of NPS staff conducting the monitoring

3) Accurate station location descriptions must be recorded and carefully followed by sampling personnel on subsequent field visits for water quality monitoring. Therefore, once on station, GPS equipment is used to obtain the station's coordinates, which allows the user to spatially reference water quality monitoring data to specific geo-referenced locations for each sampling event.

Additional uses of the GPS units may develop over time if protocols change or other needs are identified. For example, the Great Lakes Network currently promotes the use of electronic data logging equipment to enhance data quality and simplify data management. Many water quality parameters (e.g., pH) are now primarily recorded with electronic data logging equipment, while others (Secchi disk depth, names of observers, etc.) are logged on hardcopy only. Therefore, GPS units capable of logging more information other than just waypoints (e.g., Trimble GeoXT) could be programmed to allow for electronic recording of these parameters. The next two sections of this SOP will outline some of the more common and pertinent functions associated with mapping and recreational-grade GPS units, which are the types of units currently used by GLKN staff for water quality monitoring.

3.2 Using Mapping-Grade GPS Units

All mapping-grade GPS users should become familiar with GLKN GPS collection procedures and relevant manufacturer's user guides and operating manuals before GPS operation. For example, prior to using a Trimble GeoXT (mapping-grade) GPS unit, the following documents should be reviewed:

- Appendix A of this SOP
- GeoExplorer CE Series: Getting Started Guide
- GPS Mapping for GIS with TerraSync and GeoExplorer CE Series or TerraSync Operation Guide v2.4x
- Basic GPS Data Capture Using TerraSync: A Quick Start Guide

Mapping-grade GPS units provide the user with a variety of tools for field data collection. GLKN encourages the use of these units for most projects. These units can be used to acquire spatial data related to points, lines, and polygons along with associated, user defined, tabular attributes. Careful forethought and advanced planning are required to take advantage of these capabilities long before data collection begins.

3.2.1 Data Dictionaries

TerraSync software on mapping-grade GPS units is capable of using data dictionaries. Data dictionaries define the structure and rules to store attribute information about the feature being mapped and are customized for each project. GLKN data management personnel should be directly involved in the creation of data dictionaries. Basic steps include:

1) Identify the features to be mapped. These features are real world physical locations of objects (e.g., a water quality monitoring station) that are categorized as point, line, or polygon features.
2) Identify the attributes to be collected for each feature while in the field and create a data dictionary. Part of this process is assigning a unique identifier to each feature. (For example, if a survey plot is mapped as both a point and a polygon, one feature should be named plotname_poly and the other plotname_pt.)
3) Implement and test the data dictionary. Field staff should conduct a complete trial run for newly-created data dictionaries before beginning field work. Corrections and refinements are inevitable after such a trial.

Because most of the data for water quality monitoring on inland lakes are recorded by electronic sampling equipment, there has not been much incentive to utilize data dictionaries. However, as discussed earlier, it is possible that the few parameters not currently logged electronically could be incorporated into a data dictionary and recorded. As stated above, it is highly recommended that GLKN data management personnel be involved in this process, and that once created, the data dictionary only be altered with permission from data management personnel. This will reduce the potential for confusion and mistakes when data are processed at the end of the field season.

3.2.2 GPS Settings

Positional accuracy of GPS data can be affected by several factors that can be monitored and recorded with mapping-grade GPS units. Table 1 lists these factors, their definitions, and the standard settings for GLKN field work. All spatial data collected shall be analyzed for spatial accuracy and shall meet or exceed the National Map Accuracy Standards (Table 1 in Appendix A, and http://mapping.usgs.gov/standards/). Table 2 indicates the coordinate system settings for data collection in GLKN parks.

Table 1. GPS receiver settings, definitions, and standards for use at GLKN parks.

Setting Name	Definition	GLKN Setting Standard
Almanac	File containing estimated position of satellites, time corrections, and atmospheric delay parameters	Acquired automatically by GPS unit or from online sources within 10 days prior to GPS field work
Altitude reference	Ellipsoid model	Height above Ellipsoid (HAE) (preferred) or Mean Sea Level: if MSL is used, indicate Geoid Model
Antenna height	GPS antenna height above the ground	Variable, usually 1.0 meters for handheld and 1.5 m for backpack
Datum	Geodetic model designed to fit a point on the earth's surface to an ellipsoid	NAD 83 (CONUS) [preferred] WGS 84 [GPS default, as fallback] NAD 83 (CONUS) (CORS 96) [for H-Star use with GeoXH Trimble GPS Unit]
Elevation mask	The minimum angle above the horizon at which a GPS receiver will track a satellite	15 degrees
Feature types	Geometry of spatial data	GIS native formats; point, line and polygon are preferred
Logging interval	Time interval between the recording of individual GPS fixes	Points: 1 second Lines and Polygons: 5 seconds, but 1 second in some circumstances
Minimum fixes for point positions	Number of GPS fixes that are used to calculate a single position for a point feature	50 fixes (120 points in the case of GeoXH)
Mode	2 dimensional for horizontal positions and 3 dimension with an elevation position	3-dimensional (4 satellite minimum)
PDOP mask	Positional Dilution of Precision, a GPS quality estimate based on satellite geometry	6.0 or less
Real-time settings	GPS unit may be capable of performing differential correction of data during collection	Select Integrated WAAS (unless using H-star, e.g., XH unit); setting will be 'auto' or 'on'
Satellite vehicles	Number of satellites used for position fixes	4 minimum
SNR mask	Signal-to-Noise ratio is a measure of the satellite signal relative to background noise	4.0 minimum, 6.0 or greater preferred
Unit of measure	Linear unit of measure	Meter (metric)

GPS signals are received in the WGS84 datum. Processing and transformation of the positional information to other datums can take place internally in the GPS unit or in software, either the GPS data processing software (see below) or in GIS software. GPS data that will receive no post-processing differential correction, unlikely with a mapping grade receiver, can be collected in native WGS84 or NAD83 (CONUS), and ensuring that the datum used is recorded in the metadata. More likely with a mapping grade receiver, the GPS data will be differentially corrected after collection using data from one or more reference base stations. Data on the GPS unit should be collected in the same datum as the data are output from the reference base stations. The majority of public base stations in the US are part of the National Geodetic Survey's Continuously Operating Reference Station (CORS) network; and output information in the NAD83 (CONUS) CORS datum. Setting the GPS unit to record data in NAD83 (CONUS) CORS datum will result in the most accurate spatial information when differentially corrected against a CORS base station. A very high precision mapping grade unit may use H-Star technology, which requires post collection differential correction; using the NAD83 (CONUS) CORS datum and no real-time correction (WAAS) on the GPS unit, and correcting against a group of CORS base stations is necessary to realize the maximum accuracy from an H-Star receiver.

Table 2. Coordinate system settings for Great Lakes Network parks. **Bold font** indicates parks where water quality monitoring on inland lakes will take place.

Park	UTM Zone	Datum
APIS	**15**	**NAD 1983 (Conus)**
GRPO	16	NAD 1983 (Conus)
INDU	**16**	**NAD 1983 (Conus)**
ISRO	**16**	**NAD 1983 (Conus)**
MISS	15	NAD 1983 (Conus)
PIRO	**16**	**NAD 1983 (Conus)**
SACN	15	NAD 1983 (Conus)
SLBE	**16**	**NAD 1983 (Conus)**
VOYA	**15**	**NAD 1983 (Conus)**

Before beginning data collection, the GLKN data management staff or the GPS user should complete some mission planning tasks. If high accuracy fixes are desired and there is some flexibility in scheduling of a field data collection mission, the user should complete a satellite survey to determine the best timing of the mission, usually when the most satellites are visible and in the best geometry. Software, such as Trimble's Quick Plan (also included in Pathfinder Office) can be used to look for time windows that should offer the lowest PDOP readings, and thus the highest positional accuracy.

If a project requires navigation to preset locations or waypoints, this information must be pre-loaded onto the GPS hardware before starting a field data collection mission, unless the locations have been previously stored on the GPS. Having printed copies of bathymetric maps with sampling sites marked is a good backup and can maximize field time and efficiency. Some of the sampling stations on inland lakes are located relative to unique shoreline features (e.g., rock

outcrop, island, bay), which are annotated on topographic maps. Detailed descriptions and photographs of the shoreline are also used to navigate to designated sampling sites.

Many mapping-grade GPS units have the capability of storing and displaying background maps or GIS layers, which can be helpful when navigating in the field. For example, topographic maps of Isle Royale can be used with GPS units to find lakes that are off-trail. The GLKN data management staff can support preparation of these background layers and, if necessary, assist in loading them onto the GPS hardware.

GPS units create files to store data during a field session using a prefix and date-time stamp as file names. For example:

RMMDDHHx
R – Unit Prefix
MM – Month
DD – Day
HH – Hour
X – a, b, c, etc., the order files are created within an hour

If multiple GPS units are used for a project, a unique prefix (letter) should be assigned to each unit, which will ensure that downloaded files for each unit contain a unique identifier within the filename. For example, with three GPS units, the unique letters for the units could be N, G, and A. Those letters would serve as a prefix for the file n (e.g., N102715A, G102715A, and A102715A would indicate units N, G, and A, October 27, 15 hour, A first in hour). In addition, if a data dictionary is used, and entry of the observer's name or initials is not an option in the dictionary, then the observer's name or initials should be included in the file name.

Each user should be familiar with the capabilities of the GPS hardware and field computers. If possible, water quality monitoring staff should receive hands-on instruction from someone familiar with the equipment. At a minimum, the equipment user guides and operator's manuals should be reviewed, and the operator should test the functions s/he intends to use.

It is extremely important that each user become familiar with the battery power and memory capabilities of the GPS units. All units have limited battery and memory resources; these features should be thoroughly tested to gain an understanding of the power and memory limitations of the GPS units before being deployed in the field. It is possible to power or recharge these units from a DC power source, such as a vehicle power outlet.

3.2.3 Data Collection

Data collection should be performed using an approved data dictionary or database for the protocol, if applicable. Moreover, users should be mindful of the following concepts:

- If using a GPS unit that gives an approximate 5m horizontal accuracy, the user cannot map anything as a polygon that is less than 4 to 6m in width or diameter. Such objects must be captured as point features.
- If a GPS user is collecting a line or polygon feature and then stops moving, the GPS unit

will continue to collect data (Figure 1, examples 1 and 2). Users need to be familiar with the *Pause/Resume* toggle key and use it liberally. This technique greatly improves subsequent data quality and reduces the need for time-consuming spatial editing.

- Another way to avoid errors is to collect point features that represent the beginning and end points of a line transect (Figure 1, examples 3 and 4). Having these reference point locations will mean easier editing of any zig-zagging line features.

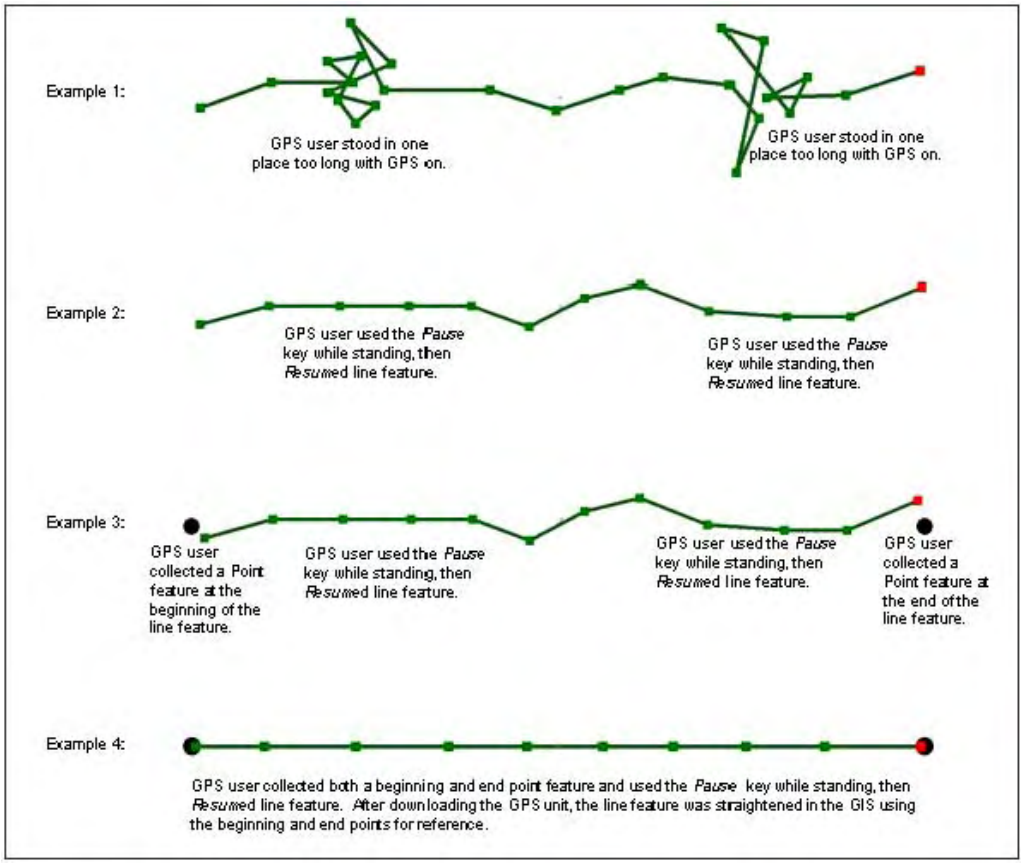


Figure 1. Examples of GPS point and line features data collection.

Mapping-grade GPS units have additional features that aid in data collection. These include:

- *Nested Features* – Allows user to collect a point while collecting a line or polygon feature. For example, while surveying potential amphibian habitat along a stream (line feature), the user can pause the line feature, take a point for a specific observation, then resume the line feature collection.
- *Offset Feature* – Allows user to collect a feature when topography is such that getting next to or over the feature is impossible. For example, a GPS line could be collected while taking a horizontal zooplankton tow off the side of a boat.
- *Between-feature Positions* – the GPS unit collects positions without any feature or attribute data. This feature is useful for tracking areas traveled during a day. For example, while surveying for presence or absence of invasive plants, a user could collect data on the area surveyed in addition to locations of specific plants found.

3.2.4 Data Processing

When data collection is complete for the day or round of sampling, data are downloaded from the GPS unit to a computer. For Trimble GPS units, the proprietary software Pathfinder Office (or the GPS Analyst extension) is used to download, differentially correct, and then export the data to a GIS format. [Note: Trimble Pathfinder Office and GPS Analyst are relatively expensive. However, Trimble also offers a free data transfer utility to download data from the GPS units to a Windows-based PC]. Differential correction is a post-processing procedure to improve upon raw GPS positions using base station data. Base stations consist of a GPS antenna and receiver positioned at a known location specifically to collect data from satellites. The distance between the base station(s) and the remote GPS receiver should be kept to a minimum.

Differential correction should be conducted on all GPS data collected, even if data were collected using the real-time collection feature. Once the data are differentially corrected, they can be verified and edited. Unintentional features can be deleted and attributes can be reviewed.

The last step in processing data is exporting the data set to GIS (ArcGIS or ArcView). Depending on the software used for this process, newly created files generated when exporting data are often assigned generic names. For example, if Pathfinder Office is used to export a file named 'VOYA2007.cor' (.cor denotes that the file has already been differentially corrected) that only contains point features, the exported file will be named 'point_ge.shp'. Great care should be taken to not overwrite this file when exporting other data, as the software will continue to use this generic naming convention the next time it is used. In addition, during the export process, the coordinate system to which the data will be exported to should be verified (Table 2).

Additional data attributes can be included in the data exports. Data attributes recommended by GLKN are listed in Table 3.

Table 3. Recommended fields to be exported in addition to GPS features.

All Features	Point Features	Line Features	Area Features
PDOP	Height	Length (2D)	Area (2D)
Correction status	Position	Length (3D)	Perimeter (2D)
Receiver type			Perimeter (3D)
Date recorded			
Data file name			
Total positions			
Data dictionary name			

Managing the incoming GPS data can be a challenge, especially if there are multiple units per project. Common practices used by GLKN include:

- Download all data to a computer or network drive that is regularly backed up.
- Keep GPS data and GIS data separate through electronic file management.
- Directories and files names should not contain non-alpha-numeric characters and/or

spaces (except underscores).
- Keep GPS data in well-organized directories (see Hart and Gafvert (2005), GLKN Data Management Plan, for more details).

At the end of a project, all data and background files should be removed from the GPS unit to free available memory. Data files should not be left on a unit if they have been properly downloaded and verified. In addition, some GPS units require their batteries to be re-charged periodically. Failure to do so can cause the GPS unit batteries to discharge completely, and may cause some files and software to be deleted.

Additional information can be found at **http://www.nps.gov/gis/gps/gps4gis/** , which describes the steps outlined here in greater detail.

3.3 Using Recreational-Grade GPS Units

Recreational-grade GPS units can be used to acquire location information (generally points) when spatial accuracy is not paramount to the project. Recreational GPS units do not have data dictionaries for storing attribute information with the point location. However, using a recreational-grade unit to capture a waypoint at each sampling site is a reliable means to verify the correct sampling site has been reached, even if a GPS location is not needed.

As with mapping-grade GPS units, personnel that employ recreational-grade GPS units should become familiar with GLKN GPS collection procedures and relevant manufacturer's user guides and operating manuals before GPS operation. For example, prior to using a Garmin 76S (recreational-grade) GPS unit, the following documents should be reviewed:

- Appendix A of this SOP
- GPSMAP 76S Quick Start Guide
- GPSMAP 76S Owner's Manual and Reference Guide
- Garmin MapSource™ User's Manual and Reference Guide

3.3.1 Planning

If a recreational-grade GPS meets the criteria of the project, the unit chosen must have the capability of downloading collected data to a personal computer. Downloading data is usually accomplished with a parallel or USB cable connection.

Much of the data collected by GPS will eventually reside in a relational database. Each GPS feature collected should contain a unique identifier that relates the feature to an associated record in a database. For water quality monitoring on inland lakes, the records associated with each GPS feature will consist primarily of water quality parameters. Since recreational GPS units have only one text field for input, careful consideration should be given to the use of this field and the design of unique identifiers. GLKN data management and GIS staff can assist in creating unique IDs on a project-by-project basis.

3.3.2 Data Collection

Location data are captured by recreational-grade GPS units as *waypoints*. When taking a waypoint, enter the site ID or site designation in the text field provided. It is also good practice to collect reference points at regular intervals. These reference point positions should be taken at known locations (e.g., trailheads, parking lots, stream confluences) which can later be used in GIS to check the accuracy of waypoint data.

If navigation to preset waypoints is applicable to a project, the waypoints must be loaded onto the GPS unit before departure to the field. Some recreational grade GPS units have the ability to store and display topographic maps, which can aid in navigation. Printed topographic maps of the waypoint locations can also be used to maximize field time and efficiently navigate between waypoints.

3.3.3 Data Processing

Data should be downloaded from GPS units once a day or after each field session. The DNR Garmin freeware product: (**http://www.dnr.state.mn.us/mis/gis/tools/arcview/index.html**) can be used to download data from Garmin GPS units. Data should be downloaded both as a text file and a shapefile. Each file name should include the download date. Points should be checked for reasonable spatial accuracy and errors. Subsequent downloads should be error-checked in the same manner. When data collection is finished, all files should be compiled into one spatial file, and along with the raw downloads, should be saved to the appropriate location on Great Lakes Network servers (refer to SOP #8, Data Entry and Management for more detail).

3.4 Metadata

Regardless of the type of GPS unit used to collect data, all resulting GIS datasets need to have information documenting how the GPS data were collected. NPS requires that FGDC (Federal Geographic Data Committee, **www.fgdc.gov/index.html**) compliant metadata be written for all geospatial layers created (Executive Order 12906).

Until final FGDC metadata is written, the data collection and management process is incomplete. Tracking GPS projects depends on the complexity of the project, how many participants, length of project etc. Documentation can be a simple 'readme' text file, or a detailed daily log.

The Great Lakes Network recommends formal metadata be written by the data collectors, as they are the ones familiar with the project and resulting data. However, Network data management and GIS staff usually end up documenting someone else's work. Chapter 7 of the GLKN Data Management Plan (Hart and Gafvert 2005) includes a detailed discussion of metadata procedures. At a minimum, the following details should be documented to facilitate final FGDC metadata:

- Name of project
- Name(s) of data collectors
- EHE/EPE or maximum PDOP (using 4 satellites)

- Coordinate system (projection, datum, and zone)
- Type (or types) of GPS units used
- The range of field collection dates
- Name of base station(s) used for differential correction
- Name and version of software used for downloading
- Any major editing performed on the raw data (e.g., moving of points)
- All versions of data dictionaries used

3.5 GPS and NPSTORET

Water quality data, including chemical, physical, and biological data, are managed according to guidelines from the NPS Water Resources Division. These guidelines include using the NPSTORET desktop database application to help manage data entry, documentation, and transfer. The Network oversees the use of NPSTORET according to the Network's water quality monitoring protocols and ensures the content is transferred at least annually to NPS Water Resource Division for upload to the EPA STORET (STOrage and RETrieval) database.

NPSTORET requires that every water quality monitoring station location must have an assigned latitude and longitude coordinate. Also, the horizontal datum to which these coordinates are referenced (typically North American Datum 1983 or World Geodetic System 1984) and the method by which they were obtained (GPS, map interpolation, etc.) must be provided. Therefore, the GLKN project leader for monitoring water quality on inland lakes and the GLKN data manager collaborate in organizing monitoring station coordinates in an acceptable format (e.g., Excel spreadsheet or Access database) to be imported to the NPSTORET database. A detailed discussion on using the NPSTORET database is found in SOP #8, Data Entry and Management.

3.6 QA/QC

Long-term monitoring is only useful if stakeholders have confidence in the data. Efforts to detect trends and patterns in ecosystem processes require high-quality, well-documented data that minimize error and bias. Data of inconsistent or poor quality can result in loss of sensitivity and lead to incorrect interpretations and conclusions.

NPS Director's Order #11B: Ensuring Quality of Information Disseminated by the National Park Service (www.nps.gov/policy/DOrders/11B-final.htm) specifies that information produced by the NPS must be of the highest quality and based on reliable data sources that are accurate, timely, and representative of the most current information available. Therefore, GLKN will establish and document procedures for quality assurance (QA) and quality control (QC) to identify and reduce the frequency and significance of errors at all stages in the data life cycle (see SOPs #8 and #12 for details on data management and QA/QC, respectively). Under these procedures, the progression from raw data to verified data to validated data implies increasing confidence in the quality of those data. Quality assurance and quality control procedures will document internal and external review processes and include guidance for addressing problems with data quality.

Examples of general of QA/QC practices include:

- Standardized field data collection forms
- Use of field computers and automated data loggers
- Proper calibration and maintenance of equipment
- Training of field crew and data technicians
- Database features such as built-in pick lists and range limits to reduce data entry errors
- Automated error-checking routines

Many of the standard operating procedures associated with the protocol for monitoring water quality in inland lakes include a discussion of QA/QC as it relates to the protocol. Examples of QA/QC practices pertaining to use of GPS include:

- Ensure that GPS-related software is periodically updated as it becomes available and has been tested.
- Record location positions on field data forms as well as with the GPS unit.
- For each monitoring station, compare location positions for different sampling events, including the position recorded during establishment of the monitoring station. This will allow for an assessment of position accuracy over time.
- If data dictionaries are used with mapping-grade GPS units, ensure that the coordinates for the monitoring station match the other attributes recorded on the GPS unit for that monitoring station.
- Check to see if the accuracy of the GPS unit meets or exceeds the National Map Accuracy Standards shown in Table 1 of Appendix A.
- Ensure that the appropriate coordinate system is used when collecting and exporting data.
- Use mapping software (e.g., Pathfinder Office or ArcGIS 9.x) to view waypoints (or features) overlaid on a geo-referenced air photo or topographical map to check for accuracy.
- If applicable, check the accuracy of the attribute(s) recorded on a GPS unit by using mapping software (see bullet above) and look-up tables or in spreadsheets generated after post-processing is complete.

A final report on data quality, including data collected by GPS, will be incorporated into the documentation for this project. Such documentation will include a listing of the specific methods used to assess data quality and an assessment of overall data quality prepared by the project manager. This is a necessary part of the data quality elements of the metadata file.

3.7 Literature Cited

Hart, M., and U. Gafvert. Editors, 2005. Data management plan: Great Lakes Inventory and Monitoring Network. National Park Service Great Lakes Inventory and Monitoring Network Report. GLKN/2005/20.

Elias, J.E., R. Axler, and E. Ruzycki. 2008. Water quality monitoring protocol for inland lakes, Version 1.0. National Park Service, Great Lakes Network, Ashland, Wisconsin. Natural Resources Technical Report NPS/MWR/GLKN/NRTR—2008/109. National Park Service, Fort Collins, Colorado.

Appendix A

This appendix discusses the role of GPS in GLKN data management and provides an explanation of the types of GPS units that are available. The text is taken directly from the GLKN GPS Field Collection Guide, which can be found in its entirety in Appendix K of the Great Lakes Inventory and Monitoring Data Management Plan (Hart and Gafvert 2005).

Introduction

Over the past decade new tools have been developed to help researchers collect and manipulate data while in the field. Global Positioning System (GPS) is one such tool. GPS is currently a constellation of 28 US Department of Defense satellites (as of 2006) orbiting 11,000 miles above the Earth, making a complete orbit approximately every 12 hours, and transmitting signals to Earth at precisely the same time. The position and time information transmitted by these satellites is used by a GPS receiver to triangulate a location coordinate on the earth using three or more satellites.

Role of GPS in GLKN Data Management

Data collected using GPS-enabled equipment represents all or part of the acquisition stage of an information resources lifecycle that includes several other stages (see Section 5.4 in GLKN Data Management Plan). The process and methodology used for acquisition, planning, data collecting, and post-processing incorporate several aspects of data management, including quality assurance, data storage and organization, and data stewardship. To promote data quality and simplify data management, the Great Lakes Network expects to use electronic data logging equipment for some data acquisition. However, parallel or complementary use of hand written data sheets and field notes will remain important for data collection activities.

Types of GPS Units

At the most basic level GPS equipment can just consist of a GPS antenna and the associated signal processing circuitry. The antenna can be a standalone device, be incorporated in to a handheld unit, or be integrated into a larger electronic device, such as a personal data assistant (PDA), data logger, or portable computer. As technology evolves, the Great Lakes Network will continually try to use equipment which maximizes spatial accuracy; reduces hardware weight and user fatigue; and reduces database development, data manipulation, and transformation.

There are three major types of GPS units that are based on the level of accuracy to which spatial data can be collected. Survey-grade GPS units are used for surveying tasks that require very high accuracy (1 cm or less). Mapping-grade units can map features from sub-meter to less than 5m accuracy, employing differential correction. Recreational-grade GPS units are sold primarily for outdoor sports and recreational activities. Accuracy using recreational GPS units ranges from 5 to 30m. Most natural resource-related data collection requirements correspond to either the recreational-grade or mapping-grade. Figure 1 shows some of the major differences between these two types.

Deciding which type of unit to use is an essential part of project planning, and depends on the end product needed. Mapping-grade GPS units are recommended for most GLKN field work; however, for some projects recreational-grade units can meet a project's accuracy requirements and reduce the cost of field operations. The choice of GPS unit should be made by the project manager after consulting with the GLKN data management and GIS staff.

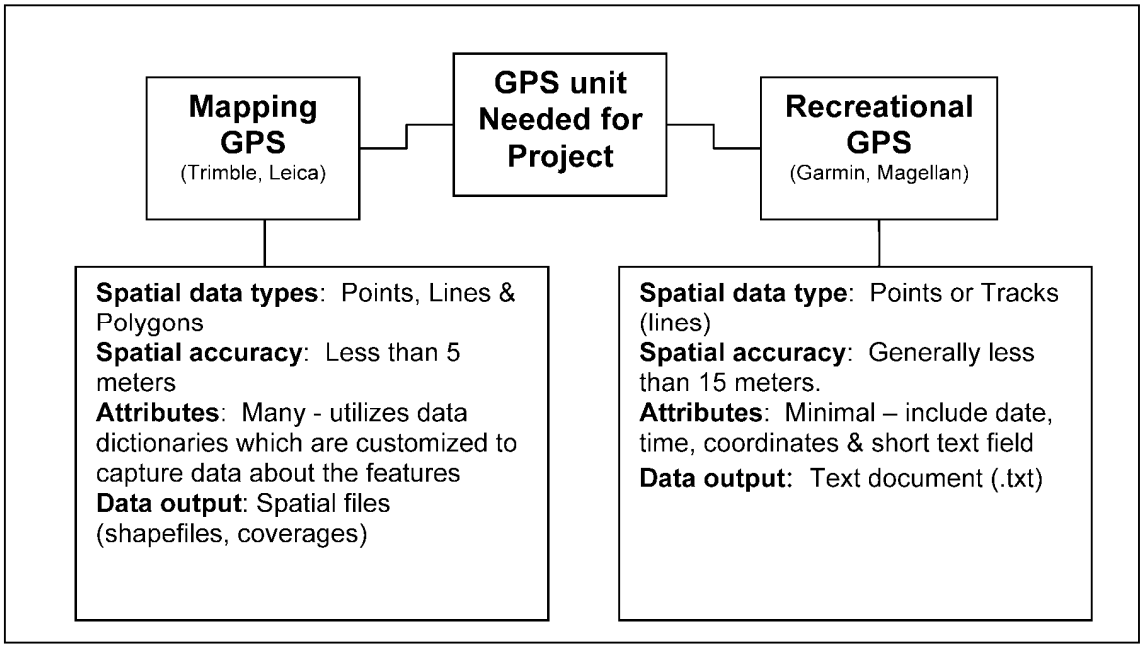


Figure 1. Differences between different grades of GPS units.

All resulting GIS data layers need to meet or exceed the National Map Accuracy Standards for a 1:24,000 product (NPS GIS Data Standards, 2002 http://www.nps.gov/gis/data_info/standards.html). Table 1 provides the allowable horizontal accuracy for some common scales.

Table 1. Map scales and allowable error

Scale	Allowable Error
1:40,000	33.8 meters (111 feet)
1:31,680	16.1 meters (53 feet)
1:24,000	12.2 meters (40 feet)
1:20,000	10.1 meters (33 feet)
1:12,000	6.1 meters (20 feet)
1:9,600	4.9 meters (16 feet)
1:4,800	2.4 meters (8 feet)
1:2,400	1.2 meters (4 feet)
1:1,200	0.6 meters (2 feet)

Definitions

Accuracy - The degree of conformance between the estimated or measured position, time, and/or velocity of a GPS receiver and its true time, position, and/or velocity as compared with a constant standard.

Almanac -Data transmitted by a GPS satellite, which include orbit information on all the satellites, clock correction, and atmospheric delay parameters. The almanac is used to facilitate rapid satellite vehicle (SV) acquisition. The orbit information is a subset of the ephemeris data with reduced precision.

Attribute – Tabular information about a specific feature.

Base Station - GPS files collected continuously from community base stations, local base stations, or Continually Operating Reference Stations (CORS). Gathering base files will require an internet connection and software that dials into a server that houses the base station data collected at the same time of the rover. Data stored on these servers will not be available in real-time - hence this step is conducted after field collection. Trimble users would use the Differential Correction utility supplied in Pathfinder Office.

Differential Correction - The merging of rover file data with base map data to correct position errors due to atmospheric interference. Autonomous data (rover) are collected in the field while base data are stored at the stationary base station. The two datasets are loaded into a post-processing software package where corrections are applied. This process will reduce errors in the field collected data (the rover) by correlating and correcting for known errors recorded in the base file that has the same time tag. As distance between the rover and base file increase, there is degradation in post-processed accuracy. In general, a degradation of one part per million (1ppm) occurs as the distance between the base station and rover increases. For example, one millimeter of degradation occurs for every kilometer between base and rover.

Datum (*geodetic datum*) – A mathematical model that is designed to fit a point on the earth's surface to an ellipsoid. Commonly used datums are North American Datum (NAD) 1927, and NAD 1983, modeled to represent the North American continent.

Feature - A feature is the spatial location of a physical object, or some event or phenomenon. Features are often referred to as graphic data in a GIS. Examples include a tree (point), road (line), or land parcel (polygon).

FGDC - The Federal Geographic Data Committee is a 19 member interagency committee composed of representatives from the Executive Office of the President, Cabinet-level and independent agencies who develop policies, standards, and procedures for organizations to cooperatively produce and share geographic data. (www.fgdc.gov/index.html)

Global Positioning Systems (*GPS*) – a constellation of a minimum of twenty-four satellite vehicles orbiting the earth approximately every twelve hours at an approximate pacing of sixty degrees, between 11,000 – 12,000 miles above the surface of the Earth

Lines – geographic term related to the scale that describe how a feature is drawn. Lines are linear

measures of a feature (such as a line representing a trail)

Mapping Grade – GPS receivers capable of attaining five meters of accuracy or better using differential correction.

Metadata - Data about the data. Usually comes in the form of a text or html document with information on the dataset's quality, current projection, attributes, distribution and citation. In the National Park Service, this generally implies a file compliant to the FGDC Content Standard for Digital Geospatial Metadata.

Multipath – error which occurs when a GPS signal sent from a satellite vehicle is bounced or redirected by an object, prior to reaching a GPS receiver. Multipath will cause the time it takes a GPS signal sent by a satellite vehicle to reach a GPS receiver to be inflated. This will cause inaccuracies in positions collected.

Points – geographic term related to the scale that describe how a feature is drawn. Points are single dimensional features (such as a point representing a spring).

Polygons - geographic term related to the scale that describe how a feature is drawn. Polygons have area associated with the feature (such as a circle representing a parking lot).

Projection - A method of representing the earth's three-dimensional surface as a flat two-dimensional surface. This normally involves a mathematical model that transforms the locations of features on the earth's surface to locations on a two-dimensional surface.

Post Processing – utilizing base station data, GPS software, and data acquired by a GPS receiver in the field to gain an accurate fixed position.

Triangulation - The process of determining the distance between points on the earth’s surface by dividing up a large area into a series of connected triangles, measuring a base line between two points, and then locating a third point by computing both the size of the angles made by lines from this point to each end of the base line and the lengths of these lines.

Waypoint – a named 3 dimensional position on the earth’s surface, that is, having both a latitude and longitude. Waypoints are assigned to a fixed location in the field so it can be navigated to consistently and accurately through time.

Standard Operating Procedure #4: Measuring Water Level

Version 1.0

In **Water Quality Monitoring Protocol for Inland Lakes**

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Add rows as needed for each change or set of changes tied to an updated version number					

Acknowledgements

Many thanks to Pete Penoyer, NPS-WRD, for informational material and feedback on this SOP. We appreciate the brainstorming with Larry Kallemeyn, USGS, and Chris Holbeck, VOYA, which led to the procedures we are now using in remote areas.

4.0 Introduction

An estimate or measurement of flow or water level is highly recommended by the National Park Service (NPS) Water Resources Division (WRD) (National Park Service 2002) for water quality monitoring programs. Water level data are important in understanding overall lake processes. These data help define the spatial extent of littoral zones, which are critical habitat for many aquatic organisms. Accurate volumetric estimates, hydrologic budgets, heat budgets, and mass balance budgets for chemical compounds and oxygen also require lake level data. Changes in bioaccumulation of mercury in aquatic organisms may be explained in part by lake level, as methylation rates are correlated with water level fluctuations (Sorensen et al. 2005). In reservoirs and other systems where lake level is controlled, such as Lake Kabetogema in Voyageurs National Park and Glen Lake adjacent to Sleeping Bear Dunes National Lakeshore, lake levels and discharge from the lake are controversial management issues (Kallemeyn et al. 2003, Vana-Miller 2002). Fluctuations in lake level also have importance in terms of lakeshore development and wetland conservation and function (Mitsch and Gosselink 2000).

In inland lakes, estimates or measurements of water level can be acquired through the use of a staff gage or reference mark and level. A staff gage is a ruler, usually made of enameled steel, placed in a stream or lake, and is used to measure the water level. Staff gages are usually mounted on permanent structures, such as a bridge piling, but may also be sunk into a stable bottom substrate or anchored to bedrock.

A reference mark is a permanent marking (e.g., an 'X' etched into concrete or a bolt drilled into a structure), the elevation of which is considered to be gage zero (Lipe, accessed 12/09/2005). If the elevation of the reference mark is established it is called a bench mark.

If staff gages or bench marks are not already installed and maintained by another agency, the Great Lakes Network will install reference marks for measuring water level of inland lakes.

4.1 Installing Reference Marks

Prior to installing reference marks, complete and submit a minimum tools analysis, if required by the park, and ensure that the park grants permission.

4.1.1 Site Selection

Choose a site for the reference mark that is not obtrusive from a visitor's viewpoint, yet is easy to access and relocate. The site should be above current water level by at least 1 m to accommodate a large rise in level, and relatively near the water's edge to allow viewing a stadia rod from the reference mark. Past reported water level fluctuations should be reviewed to determine an appropriate site and the maximum water level range that may be expected.

4.1.2 Installation Procedures

At lakes where large pieces of bedrock are exposed, such as at Voyageurs National Park, secure an aluminum dome-top concrete reference mark (2" top diameter, 5/8" stem diameter, 2.5" stem

length, 3 oz. weight) in the bedrock using the following steps. Drill a hole 2.5" deep into the bedrock using a rock hammer and a 5/8" drill bit. Remove the rock dust from the hole with canned air. Apply the appropriate kind of epoxy to the reference mark. Insert the reference mark into the drilled hole, and ensure proper seating by pounding it briefly with a rock or stepping on it.



Clockwise from upper left: drilling a hole into the bedrock, using canned air to blow dust from hole, reference mark in bedrock next to GPS unit ,applying epoxy to reference mark.

At lakes where bedrock is not exposed, one of the following alternatives may be used: 1) A nail in a large, long-lived tree, with known height above ground; 2) a long iron rod (~1.5 to 2 m) sunk into the ground until nearly flush with ground level, with a reference marker cemented in the top with concrete; 3) a mark on a nearby structure, such as a building, bridge, or observation deck. Installing a back-up marker will ensure a continuous data record should one marker be dislodged (e.g., frost heave or tampering).

4.1.3 Record Location of Reference Mark

Record the location of the marker with a GPS unit. Use the GPS to also record the distance to and location of a nearby landmark, such as a fire ring at a campsite. Record detailed notes in the field notebook on directions to the reference mark location so that a different field crew will be

able to find the marker in the future. Take a compass bearing and photo of the reference mark site from at least one landmark, and a compass bearing and photo of the landmark(s) from the reference mark. Ensure the compass has been set to the proper magnetic declination to get the true compass bearing.

Example of notes on location and photos of reference marker.

Reference Mark Notes – Agnes Lake

6-10-06 water level = - 1.20m UTM: 5368392N 513742E

Reference mark is on the northwest side of the lake northeast of the campsite at a straight line distance of 34.5 m. It is below a large rock wall about 1.5 m away from the water's edge beneath a 10"dbh jack pine. Hike along the shoreline to the large jack pine. Reference mark is at a 40^0 bearing from the fire ring.

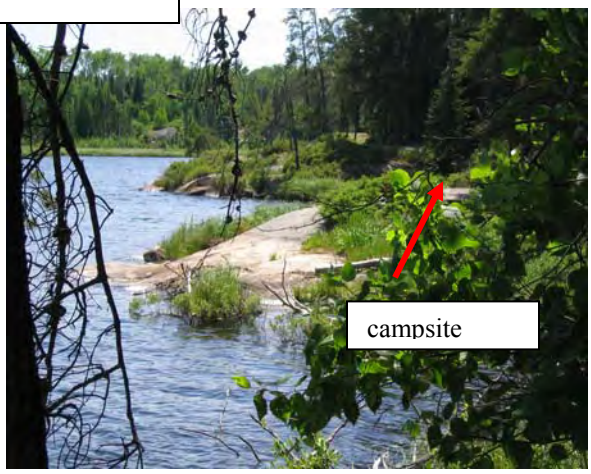
Pictures are from the campsite toward marker and marker toward the campsite.

8-2-06 water level = - 1.305 m

Agnes Lake Reference Mark



Picture of reference mark from campsite



Picture of campsite from reference mark

4.2 Measuring Water Level

The Network will always install reference markers well above current water level. The markers may become submerged, however, after extreme flooding events. For example, water levels at some lakes in Voyageurs National Park have fluctuated by over 1 m from one year to the next due to the transience of beaver impoundments (Kallemeyn, personal communication).

In some cases, the reference marker may have been installed by another agency and may be located below the current water level. Such is the case at Long Lake, Indiana Dunes National Lakeshore, where the USGS has a benchmarked groundwater well in a location that is sometimes above water level, and sometimes below water level.

Instructions for measuring water level above and below reference markers are included below. Because many of our lakes are in remote locations, we will use one of the following procedures that require a minimum of equipment. Procedures differ only in the detail; the concept is the same in all.

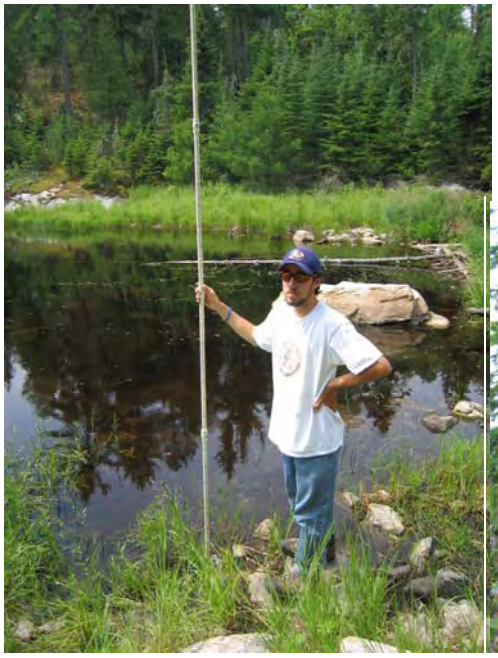
Water-level measurements at a given lake will always be based on the same reference marker. If a new reference marker has to be used, a new water level data set will be created using this new reference mark as the standard. The use of a new reference mark for measuring water level will be clearly noted in the field notebook and NPSTORET database. Water levels using different reference markers cannot be compared because the markers will likely be located at different elevations above the land-water interface.

4.2.1 Reference Marker Above Water Level

Method 1: One person stands at the water's edge and holds the base of the stadia rod at current water level while a second person at the reference marker uses an eye level to view the rod held vertically. If the reference marker is glued to the bedrock, the second person will need to get his/her eye above the rock in a stable position. A second stadia rod or metric ruler will work for this purpose. The second person looks through the eye level, first focusing the cross-hairs, then focusing on the rod held at water level. When the bubble inside the eye level is centered vertically, the instrument is being held on level. Read the height on the stadia rod. The person holding the rod can assist by sliding a finger or pencil up and down the rod until the person with the eye level sees it in the cross-hair. Record this level to the nearest 0.1 cm, then measure and record the height of the second person's eye level above the reference marker. Subtract this height from the reading of the level on the rod to get water level relative to the reference marker. The resulting number will be negative to indicate water level below reference marker.

Example:

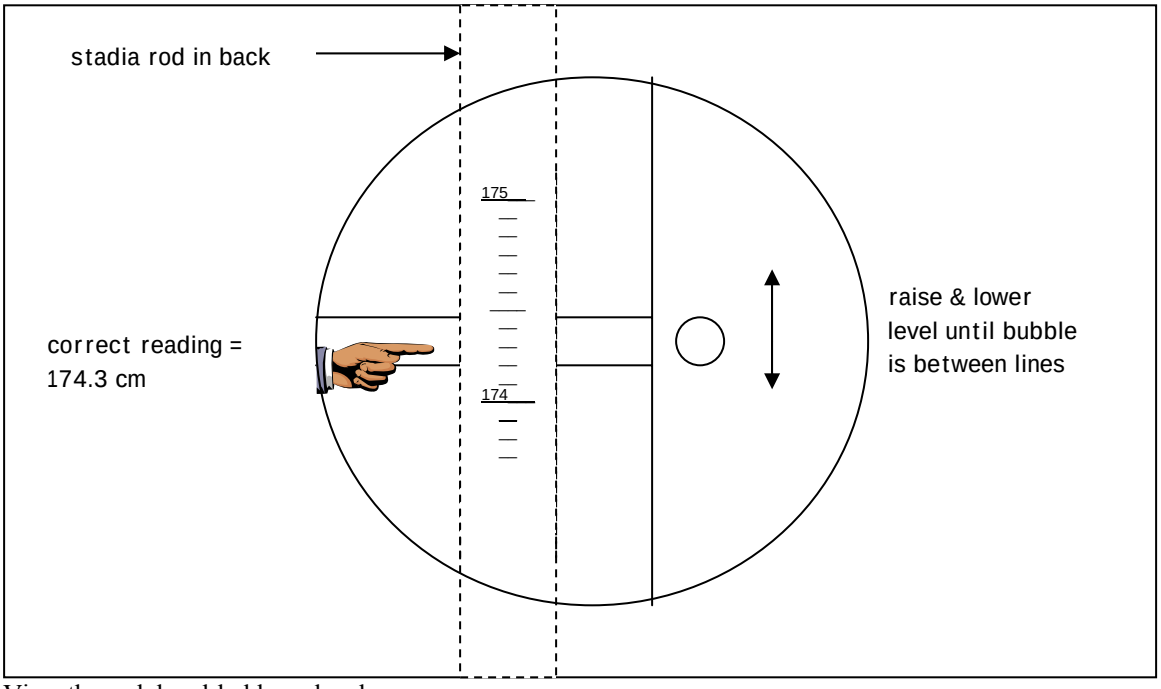
- Eye level reads 174.3 cm on the stadia rod
- Height of eye level above reference marker = 15.4 cm
- Subtract height of eye level from level on stadia rod: 174.3-15.4 = 158.9
- Water level relative to reference marker = -158.9 cm or -1.589 m.



Holding stadia rod at water's edge



Viewing stadia rod through hand-held eye level

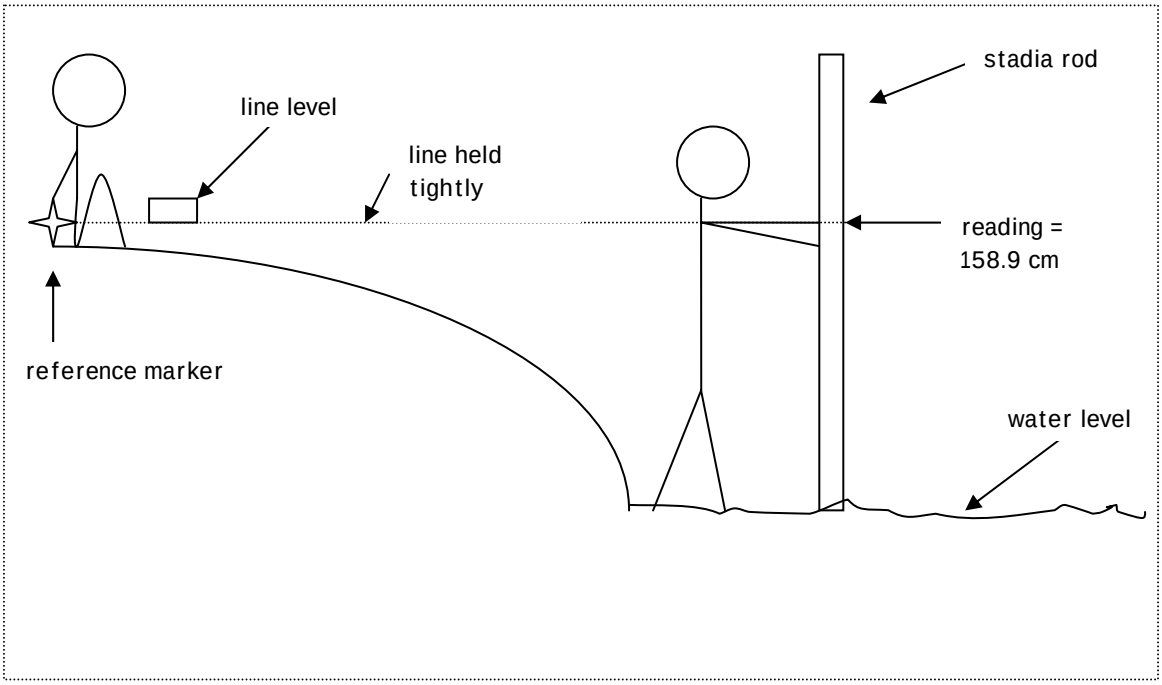


View through hand-held eye level

Method 2: One person stands at the water's edge and holds the base of the stadia rod vertically at current water level and one end of a line or cord. A second person at the reference marker holds the other end of the line on the marker and stretches it taut. Using a line level, the person holding the stadia rod adjusts the level of the line on the rod until the line is level. The reading to the nearest 0.1 cm is taken directly on the rod when the line is level and will be a negative number to indicate water level below reference marker.

Example:

- Line is level on stadia rod at 158.9 cm
- Water level relative to reference marker = -158.9 cm or -1.589 m

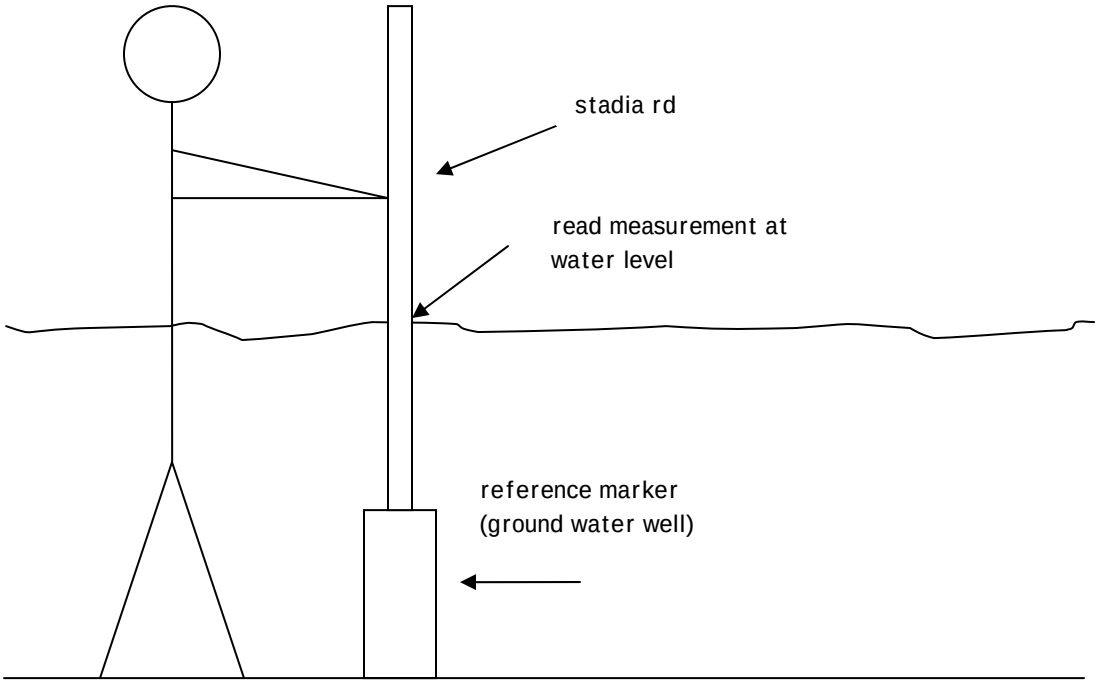


4.2.2 Reference Marker Below Water Level

From a boat or while wading, use a stadia rod held on the reference marker to read water level above marker. The reading, to the nearest 0.1 cm, will be a positive number.

Example:

- Water level on stadia rod measures 63.4 cm
- Water level relative to reference mark is 63.4 cm or 0.634 m



4.2.3 QA/QC

For quality assurance, each measurement should be repeated, with the field personnel switching roles. For example, one person will hold the stadia rod while the other will measure the water level through the eye level, then the people will change roles. Both readings should be recorded on the field data sheet, along with the average. If the repeated measurements differ by 10 cm or more, both readings should be repeated.

To minimize sources of error, use a firm surface on which to set the surveyors rod (e.g., a rock or a Secchi disk) and a firm surface on which to place the eye level (e.g., a piece of 2 x 4 lumber or the clipboard).

4.3 Equipment List

The following equipment and supplies are required for installing reference marks in bedrock and measuring water level.

Installation
aluminum dome cap markers
battery-powered hammer drill and spare battery
drill bit
canned air
epoxy
hard surface for mixing epoxy (e.g., piece of cardboard or rigid plastic)
small plastic bag for garbage
GPS unit and spare batteries

compass
field notebook

Measuring Water Level
stadia rod
eye level or line and line level
GPS unit and spare batteries
compass
field notebook
photos and description of location
data sheets
firm surfaces for placing stadia rod and eye level

If installing a reference mark using a method other than gluing it in bedrock, substitute appropriate installation materials for those listed above. For example, if pounding in an iron rod and cementing a surveyors marker to the top, the following will be needed: sledge hammer, quick-crete, water for mixing, stir-stick, bucket for mixing, iron rod, and aluminum dome cap marker.

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Standard Operating Procedure #5: Decontamination of Equipment to Remove Exotic Species

Version 1.0

In **Water Quality Monitoring Protocol for Inland Lakes**

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Revision History Log

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5.1 Introduction

Aquatic invasive species (AIS) are an issue of increasing concern nationwide. In the Great Lakes, for example, approximately 140 exotic species have invaded since the late 1800s (Great Lakes Information Network 2005) and have had enormous ecosystem effects (e.g., Dermott and Kerec 1997, Barnhisel and Kerfoot 2004, Hoff 2004, Great Lakes Commission 2005). Some of these species have invaded inland water bodies, where disruptions to native species are also documented (e.g., Jack and Thorp 2000, Indrisi et al. 2001, Compton and Kerfoot 2004). Zebra mussels (*Dreissena polymorpha*) now occur in several lakes at Sleeping Bear Dunes National Lakeshore, and the spiny waterflea (*Bythotrephes cederstroemi*) has been found in Grand Sable Lake, Pictured Rocks National Lakeshore and two of the large regulated lakes at Voyageurs National Park (Rainy and Namakan). When the parks and Great Lakes Network conduct routine water quality monitoring, it is important to ensure these aquatic exotics are not transferred from contaminated water bodies to uncontaminated water bodies.
As we implement our water quality monitoring program, we are concerned with the limited suite of AIS that can adhere to, or passively catch on, sampling equipment (including boats and trailers). This standard operating procedure (SOP) focuses on aquatic plants, zooplankton, and mussels.

At each park, we will use the Hazard Analysis Critical Control Point (HACCP) method (Gunderson and Kinuunen 2004) to identify water bodies at risk and locations where control of AIS is imperative. It is critical to integrate this SOP with monitoring for the occurrence of AIS in park lakes and rivers.

5.2 Equipment and Supplies

The sampling equipment used in routine water quality monitoring is described in SOP #6. Of particular importance in this decontamination SOP, is that nets are not currently used in routine water quality monitoring. If nets are added to the equipment used in any part of water quality monitoring, this decontamination SOP should be revised to include specific decontamination procedures for nets.

The supplies and equipment required for decontaminating sampling equipment between lakes are:

- o tap water
- o hose and sprayer nozzle
- o portable containers for lake water, such as a bucket or cubitainer
- o scrub brush
- o bottle brush on a rope

5.3 Decontamination Procedures

5.3.1 Aquatic Invasive Species Procedure Plan and Hazard Analysis Worksheet

The aquatic invasive species hazard analysis and critical control point (HACCP) worksheet is used in describing the sampling project, including types of gear, methods of transportation, steps involved in the procedure; and analyzing the potential risk of AIS transport from one water body to another, or one section of a river to another section. Details on completing the worksheet are described in the AIS-HACCP manual (Gunderson and Kinuunen 2004), and are included in Appendix A. The example included here, in Appendix B, is for Pictured Rocks National Lakeshore. The Network has modified the worksheet slightly to suit our needs. Worksheets will be completed for each park unit, and will be updated annually prior to the sampling season. Worksheets will also be updated in the following circumstances:

- change in sampling equipment or techniques
- addition of a new water body or river site to the sampling regime
- change in the order of sampling water bodies
- detection of a new AIS in a water body or section of river
- change in scientific knowledge regarding life history, potential hazard, or control of an AIS.

5.3.2 Step-by-step Procedures for Decontamination

When the hazard analysis worksheet identifies a significant AIS risk and adequate drying or freezing of equipment is not feasible (five days in the sun for boats and trailers, 10 days for other equipment, or two day of freezing; Gunderson and Kinuunen 2004), one of the two procedures below, for remote locations or locations where tap water is available, will be followed.

Procedure at remote locations

When finished at Lake 1, which is known or suspected to be infested with exotic species:

- remove and rinse mud, plant material, mussels, and other visible organic material boat/canoe, paddles/oars, boots, and from all sampling equipment;
- run hand up and down ropes attached to all equipment and anchor to dislodge mud, plant material, and organisms;
- pay particular attention to cracks and crevices in equipment when rinsing;
- visually inspect all gear to verify that all equipment and gear has been cleaned and rinsed.

Before entering Lake 2, which is not known to contain exotic species:

- use a clean and dry container, such as cubitainer or bucket to collect lake water;
- on a vegetated area away from the lakeshore, rinse and scrub with (clean) scrub-brush all sampling equipment, boat/canoe, paddles/oars, boots, etc. Avoid rinsing on impervious surfaces or slopes where rinse water might run directly into the lake;
- use a bottle brush on a rope to clean the inside of the integrated sampler;
- pay particular attention to ropes, cracks, and crevices in equipment, and rinse well;
- visually inspect all gear to verify that all equipment and gear has been cleaned and rinsed.

Procedure at non-remote locations, when tap water is available

When finished at Lake 1, which is known or suspected to be infested with exotic species:

- remove or rinse mud, plant material, mussels, and other visible organic material from boat/canoe, paddles/oars, boots, and all sampling equipment.

Before entering Lake 2, which is not known to contain exotic species:

- on a vegetated area away from the lake, use hose with spray nozzle and scrub brush to rinse and scrub with tap water and scrub-brush all sampling equipment, boat/canoe, paddles/oars, boots; discard water on land, away from lakeshore, avoiding impervious surfaces and slopes where rinse water might run directly into the lake;
- use a bottle brush on a rope to clean the inside of the integrated sampler;
- pay particular attention to ropes, cracks, and crevices in equipment, and rinse well;
- visually inspect all gear to verify that all equipment and gear has been cleaned and rinsed.

Regardless of remoteness

- When possible, avoid using boats and other equipment on both infested and uninfested waters. Designate a set of equipment for both types of waters.
- Always begin sampling with lakes not known to harbor exotic species; sample lakes known or suspected to contain exotic species last.
- Thoroughly clean or disinfect all equipment between use in infested and uninfested waters.
- When possible, allow boat/canoe and paddles/oars to dry for five days and all other sampling equipment boots to dry for 10 days after sampling a water body known to be infested with AIS.

5.4 Documentation

The original AIS-HACCP worksheet and all updates will be maintained at each park and copies will be kept at the Network office. Documents used to complete each worksheet will also be kept on file at the parks and at the Network. Examples of such supporting documentation include information used in analyzing the hazards of contamination and determining adequate prevention of AIS spread, and the most current geographic range of AIS. When the water quality monitoring protocol is integrated with monitoring for AIS, the AIS monitoring report will also be kept at each park and at the Network office.

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Appendix A. Instructions for completing a hazard analysis and critical control point plan.

The following instructions for completing HACCP Procedure Form, Potential Hazards Worksheet, Hazard Analysis Worksheet, and Plan are taken directly from the AISHACCP manual (Gunderson and Kinuunen 2004). Not all steps will apply to the Great Lakes Inventory and Monitoring Network's protocol for decontamination of water quality monitoring field equipment and gear.

Preliminary Steps

1: Document general information.

Record the name and address of your facility or agency in the spaces provided on the first page of the Hazard Analysis Worksheet and the AISHACCP Plan Form (Appendix 9).

2: Describe the cultured or wild harvested fish (if applicable).

Identify the market name or Latin name (species) of the fish.
examples:

- Fathead minnows (*Pimephales promelas*)
- Golden shiners (*Notemigonus crysoleucas*)
- White sucker (*Catostomus commersoni*)
- Walleye (*Sander vitreus*)

Fully describe the product.
examples:

- Fathead minnows graded on 16 grader
- Golden shiners graded on 21 grader
- White suckers ungraded
- Rosy red minnows from Arkansas, held in ponds until distribution
- White suckers graded on a 23 grader
- Walleye fingerlings 5 - 8 inches
- Yellow perch fingerlings 2.5 - 3 inches

For management, research, and enforcement activities:

- Completely describe research or management activities
- Describe all equipment and gear that will be used
- I dentify when and how activities will be conducted

Record this information in the spaces provided on the first page of the Hazard Analysis Worksheet and the AIS-HACCP Plan Form.

3: Describe the harvest, production, management, research, or enforcement activity.

Identify how the product or the samples are collected, stored, and distributed. Identify whether any special shipping or handling methods are used.
examples:

- Wild harvested with seines, held in tanks, graded, then trucked to retail stores
- Pond-raised, seined, then held in different ponds over the winter, trucked to retail stores

- o Pond-raised, trapped from ponds, then transferred directly to lakes for stocking
- o Anglers on three lakes are checked for violations each day for a given period of time
- o Electroshocking and seining are conducted on 10 lakes to assess year class strength

Record this information in the spaces provided on the first page of the Hazard Analysis Worksheet and the AIS-HACCP Plan Form.

4: Identify the intended use and customer (if applicable).
Identify how the product will be used.
examples:

- o Live fishing bait
- o Feeder fish (feeding pond or aquarium fish)
- o Stocking into public waters
- o Stocking into private waters
- o Stocking into aquaculture production facility (indoor or outdoor)
- o Scale and stomach samples will be brought back to the office for analysis
- o Fish will be brought back for captive brood stock

Identify your intended customer or user of the product.
examples:

- o General public
- o A wholesaler
- o A retail store
- o Fish farmer
- o State agency

Record this information in the spaces provided on the first page of the Hazard Analysis Worksheet and the AIS-HACCP Plan Form.

5: Develop a flow diagram.
The purpose of the flow diagram is to provide a clear, simple description of the steps involved in producing your fishery products or conducting your management, research, and enforcement activities. The flow diagram should cover all of the steps in the process that your firm or agency performs. The flow diagram should be verified on-site for accuracy. Examples of flow diagrams can be found in appendices 3-8.

Hazard Analysis Worksheet

6: Set up the Hazard Analysis Worksheet.
Record each of the steps from the flow diagram in column 1 of the Hazard Analysis Worksheet.

7: Identify the potential AIS-related hazards.
Record the AIS-related hazards for each step. Use your own expertise and that of others to identify AIS hazards related to your fish production, or management, research, or enforcement practices. Check with appropriate agencies to determine if the waters in which you conduct activities are infested with invasive species.

Even if you think you have effective hazard controls in place, record the hazard. For example, your equipment might be free of AIS plant material because of the: 1) absence of AIS in the area of harvest or sampling in an infested water body; or 2) existence of inadvertent hazard controls (procedures you typically use in the course of your activities that may remove AIS).

8: Complete the Hazard Analysis Worksheet.
Completing the Hazard Analysis Worksheet requires understanding potential hazards, determining if each potential hazard is significant, and identifying critical control points for each significant hazard associated with your product or activities.

AIS –HACCP Plan Form

9: Complete the AIS-HACCP Plan Form.
Copy the Critical Control Points from column 6 of the Hazard Analysis Worksheet to column 1 of the AIS-HACCP Plan Form. Enter the associated hazard(s) from column 2 of the worksheet to column 2 of the plan form. If you did not identify significant hazards and CCPs, you do not need to complete an AIS-HACCP plan.
Complete the AIS-HACCP Plan Form by designing techniques, methods, and treatments to deal with each significant hazard in column 2. For each significant hazard:

- o set critical limits
- o establish monitoring procedures
- o establish corrective action procedures
- o establish a record keeping system
- o establish verification procedures

After you completed these steps for each hazard, the AIS-HACCP plan form is finished. To signify that the AIS-HACCP plan has been accepted for implementation, the responsible individual on-site or a higher level official should sign and date the first page of the plan form.

Appendix B. An example of a plan for the control of aquatic invasive species at Pictured Rocks National Lakeshore.

AIS-HACCP PLAN

Aquatic Invasive Species - Hazard Analysis and Critical Control Point **Procedure Form**

Procedure Description

Park info:	Park name: *Pictured Rocks National Lakeshore*
	Address: *N8391 Sand Point Road* City: *Munising* State: *MI* Zip: *49862*
(if applicable):	Fish species: *NA*
Management, research, or monitoring activity:	Activity: *Water Quality Monitoring*
Method of transportation, distribution, and storage of boats, gear, etc.	Methods: *Boat and gear either trailered or portaged to public landing sites. Profiles of water temperature, dissolved oxygen, specific conductance, and pH are conducted with multi-probe sonde. Water is collected with an integrated sampler for lab analyses. Sometimes more than one lake is sampled per day.*

Procedure Flow

List the steps involved in the management, research, or monitoring activity.

Include a simple, but, complete, description of the procedure. List all steps within NPS control, but only as many steps as necessary to define the procedure.

(1)	*NPS staff drive to trail head and portage canoe into Miners L., conduct WQ monitoring with sonde, and collect water samples with integrated sampler for lab analyses. Portage canoe back to truck and drive to maintenance bldg.*
(2)	*Day 2: Trailer row boat and outboard motor, on Grand Sable L., conduct WQ monitoring with sonde, and collect water samples with integrated sampler for lab analyses. Trailer boat and motor back to maintenance bldg.*
(3)	*Day 3, trailer boat and electric motor to Little Beaver L., cross Little Beaver L. into Beaver L., cross Beaver L. and beach at trail to Trappers L. Portage inflatable boat to Trappers L., conduct sampling, deflate boat, and return to Beaver L*
(4)	*Day 3 continued: Use electric motor to reach sampling site on Beaver L., conduct sampling, as above.*
(5)	*Day 3, continued: Motor to site on Little Beaver L. and conduct sampling. Trailer boat and electric motor back to maintenance bldg.*
(6)	*Day 4, drive to parking lot and hike to Chapel L., where canoe is chained, paddle to site, and conduct sampling. Hike back to truck and drive back to office/lab.*
(7)	*At the end of each sampling day, water samples are processed back at the park lab, with the exception of Trappers L., where sample is processed in the field. Beaver L. sample may or may not be processed in the field, depending on time.*
(8)	
(9)	
(10)	
(11)	
(12)	

Next Step:
Complete the potential hazards worksheet.

Upon completion of the AIS-HACCP plan, sign here to accept plan for implementation

Name:	
Signature:	Date:

AIS-HACCP PLAN

Aquatic Invasive Species - Hazard Analysis and Critical Control Point **Potential Hazards Worksheet**

Potential AIS Hazards

List all relevant species

Examples: round goby, ruffe, carp, etc.	AIS Fish and Other Vertebrates *N/A*
Examples: zebra mussel, spiny waterflea, rusty crayfish, etc.	AIS Invertebrates *Bythotrephes cederstroemi is present in Grand Sable L., Beaver L., and probably Little Beaver L. (due to connection with Beaver L.)*
Examples: curly pondweed, Eurasian water-milfoil, etc.	AIS Plants *not known; PIRO in need of aquatic plant inventory*
Examples: whirling disease, heterosporis, etc.	AIS Pathogens *N/A*
Next Step: After identifying the potential hazards, complete a hazard analysis form.	

AIS-HACCP PLAN

Aquatic Invasive Species - Hazard Analysis and Critical Control Point **Hazard Analysis Worksheet**

(1) Activity Activity step from flow diagram, page 1	(2) Hazards Potential AIS hazards introduced or controlled at this step (from potential hazards worksheet)	(3) Are AIS hazards significant (Yes/No)	(4) Justification Justify your decisions for column 3.	(5) Control What control measures will be applied to prevent the significant hazards?	(6) CCP Is this step a critical control point? (Yes/No)
Work Flow Step (1): *NPS staff drive to trail head and portage canoe into Miners L., conduct WQ monitoring with sonde, and collect water samples with integrated sampler for lab analyses. Portage canoe back to truck and drive to maintenance bldg.*	Fish/Other Vertebrates *N/A*	*No*	*Boat and equipment used will not capture any fish.*		*No*
	Invertebrate *N/A*	*No*	*Invertebrate AIS not in Miners L.*		*No*
	Plant *Unknown*	*Unknown*	*Plant AIS not known to occur in Miners L.*	*Inspect canoe, anchor, and rope before and after sampling; remove any mud and plant material*	*Yes*
	Pathogens *N/A*	*No*	*AIS pathogens not present*		*No*
Work Flow Step (2): *Day 2: Trailer row boat and outboard motor to Grand Sable L., conduct WQ monitoring with sonde, and collect water samples with integrated sampler for lab analyses. Trailer boat and motor back to maintenance bldg.*	Fish/Other Vertebrates *N/A*	*No*	*Boat and equipment used will not capture any fish.*		*No*
	Invertebrate *Bythotrephes cederstroemi*	*Yes*	*Species present for x years. Boat and motor only used on lake(s) where this species is present.*	*After sampling, wash sampling equipment, anchor, and rope. Allow boat to dry before using on next lake.*	*Yes*
	Plant *Unknown*	*Unknown*	*Plant AIS not known to occur in Grand Sable L.*	*Inspect boat, trailer, anchor, and rope before and after sampling; remove any mud and plant material*	*Yes*
	Pathogens *N/A*	*No*	*AIS pathogens not present*		*No*

Next Step:

Once you have determined the cirtical control points of your procedure, enter them in row 1 of the HACCP plan form.

AIS-HACCP PLAN

Aquatic Invasive Species - Hazard Analysis and Critical Control Point **Hazard Analysis Worksheet**

(1) Activity Activity step from flow diagram, page 1	(2) Hazards Potential AIS hazards introduced or controlled at this step (from potential hazards worksheet)	(3) Are AIS hazards significant (Yes/No)	(4) Justification Justify your decisions for column 3.	(5) Control What control measures will be applied to prevent the significant hazards?	(6) CCP Is this step a critical control point? (Yes/No)
Work Flow Step (3) *Day 3, trailer boat and electric motor to Little Beaver L., cross Little Beaver L. into Beaver L., cross Beaver L. and beach at trail to Trappers L. Portage inflatable boat to Trappers L., conduct sampling, deflate boat, and return to Beaver L*	Fish/Other Vertebrates *N/A*	*No*	*Boat and equipment used will not capture any fish.*		*No*
	Invertebrate *Bythotrephes cederstroemi*	*Yes*	*Species present in Beaver L. and probably in Little Beaver L.*	*Conduct sampling on Trappers L.1st. Waders used in Beaver L. will not be used in Trappers L.*	*Yes*
	Plant *Unknown*	*Unknown*	*Plant AIS not known to occur in Trappers, Beaver, or Little Beaver Lakes.*	*Inspect both boats, electric motor, trailer, anchor, and rope before and after sampling; remove any mud and plant*	*Yes*
	Pathogens *N/A*	*No*	*AIS pathogens not present*		*No*
Work Flow Step (4): Day 3 continued: Use electric motor to reach sampling site on Beaver L., conduct sampling, as above.	Fish/Other Vertebrates *N/A*	*No*	*Boat and equipment used will not capture any fish.*		*No*
	Invertebrate *Bythotrephes cederstroemi*	*Yes*	*Species present in Beaver L. and probably in Little Beaver L.*	*No control needed until after step 5 because Trappers L. does not harbor species and Beaver L. is connected to Little*	*No*
	Plant *Unknown*	*Unknown*	*Plant AIS not known to occur in Trappers, Beaver, or Little Beaver Lakes.*	*No control needed until after step 5 because boat/anchor not used onTrappers L;Beaver L. is connected to Little*	*No*
	Pathogens *N/A*	*No*	*AIS pathogens not present*		*No*

Next Step:

Once you have determined the cirtical control points of your procedure, enter them in row 1 of the HACCP plan form.

AIS-HACCP PLAN

Aquatic Invasive Species - Hazard Analysis and Critical Control Point **Hazard Analysis Worksheet**

(1) Activity Activity step from flow diagram, page 1	(2) Hazards Potential AIS hazards introduced or controlled at this step (from potential hazards worksheet)	(3) Are AIS hazards significant (Yes/No)	(4) Justification Justify your decisions for column 3.	(5) Control What control measures will be applied to prevent the significant hazards?	(6) CCP Is this step a critical control point? (Yes/No)
Work Flow Step (5) *Day 3, continued: Motor to site on Little Beaver L. and conduct sampling. Trailer boat and electric motor back to maintenance bldg.*	Fish/Other Vertebrates *N/A*	*No*	*Boat and equipment used will not capture any fish.*		*No*
	Invertebrate *Bythotrephes cederstroemi*	*Yes*	*Species present in Beaver L. and probably in Little Beaver L.*	*After sampling, wash sampling equipment, anchor, and rope. Allow boat to dry before using on next lake.*	*Yes*
	Plant *Unknown*	*Unknown*	*Plant AIS not known to occur in Trappers, Beaver, or Little Beaver Lakes.*	*Inspect boat, electric motor, trailer, anchor, and rope after sampling; remove any mud and plant material*	*Yes*
	Pathogens *N/A*	*No*	*AIS pathogens not present*		*No*
Work Flow Step (6) *Day 4, drive to parking lot and hike to Chapel L., where canoe is chained, paddle to site, and conduct sampling. Hike back to truck and drive back to office/lab.*	Fish/Other Vertebrates *N/A*	*No*	*Boat and equipment used will not capture any fish.*		*No*
	Invertebrate *N/A*	*No*	*Invertebrate AIS not in Chapel L.; canoe kept at lake and used here only.*		*No*
	Plant *Unknown*	*Unknown*	*Plant AIS not known to occur in Chapel L.; canoe kept at lake and used here only.*	*Inspect anchor rope before and after sampling; remove any mud and plant material*	*Yes*
	Pathogens *N/A*	*No*	*AIS pathogens not present*		*No*

(add additional pages as needed)

Next Step:

Once you have determined the cirtical control points of your procedure, enter them in row 1 of the HACCP plan form.

AIS-HACCP PLAN

Aquatic Invasive Species - Hazard Analysis and Critical Control Point **Hazard Analysis Worksheet**

(1) Activity Activity step from flow diagram, page 1	(2) Hazards Potential AIS hazards introduced or controlled at this step (from potential hazards worksheet)	(3) Are AIS hazards significant (Yes/No)	(4) Justification Justify your decisions for column 3.	(5) Control What control measures will be applied to prevent the significant hazards?	(6) CCP Is this step a critical control point? (Yes/No)
Work Flow Step (7) *At the end of each sampling day, water samples are processed back at the park lab, with the exception of Trappers L., where sample is processed in the field. Beaver L. sample may or may not be processed in the field, depending on time.*	Fish/Other Vertebrates *N/A*	*No*	*Boat and equipment used will not capture any fish.*		*No*
	Invertebrate *Bythotrephes cederstroemi*	*No*	*As part of sample processing procedure, all apparatus is rinsed thoroughly with distilled water, followed by a rinse with sample water.*		*No*
	Plant *Unknown*	*No*	*Processing equipment used will not transfer plant AIS*		*No*
	Pathogens *N/A*	*No*	*AIS pathogens not present*		*No*
Work Flow Step (8)	Fish/Other Vertebrates				
	Invertebrate				
	Plant				
	Pathogens				

(add additional pages as needed)

Next Step:

Once you have determined the cirtical control points of your procedure, enter them in row 1 of the HACCP plan form.

AIS-HACCP PLAN

Aquatic Invasive Species - Hazard Analysis and Critical Control Point **AIS-HACCP Plan Form**

Critical Control Point Each row answered "yes" in column 6 of Hazard Analysis Form	**(1)** *NPS staff drive to trail head and portage canoe into Miners L., conduct WQ monitoring with sonde, and collect water samples with integrated sampler for lab analyses. Portage canoe back to truck and drive to maintenance bldg*	*Day 2: Trailer row boat and outboard motor to Grand Sable L., conduct WQ monitoring with sonde, and collect water samples with integrated sampler for lab analyses. Trailer boat and motor back to maintenance bldg.*
Significant Hazards as determined in column 3 of Hazard Analysis Form	**(2)** *The presence of plant AIS is unknown. If present, species could be transported from an infested lake to an uninfested lake.*	*Sampling equipment and anchor rope could have Bythotrephes stuck, which could get be transported to another lake.*
Limits for Each Control Measure	**(3)** *No viable plant parts remain on canoe or other equipment.*	*No viable zooplankton remain on equipment, including anchor rope.*
Monitoring Describe what is being monitored	**(4)** *Presence of exotic plant material. Ensure that canoe and all equipment is free of viable plant parts.*	*Presence of exotic zooplankton. Ensure that all equipment is free from zooplankton.*
Explain how the monitoring will take place	**(5)** *Visual inspection of canoe and other equipment for plant fragments.*	*Visual inspection of equipment for zooplankton.*
Frequency of monitoring	**(6)** *Each time, before and after equipment is used in a lake.*	*Each time, after equipment is used in Grand Sable.*
Person or position responsible for monitoring	**(7)** *Water quality monitoring staff.*	*Water quality monitoring staff.*
Corrective Actions Actions taken when limits of control measures are not met	**(8)** *Cease operation and clean equipment before launching onto water.*	*Clean equipment again, and inspect again.*
Verification Method of verification	**(9)** *Review records.*	*Review records.*
Records List what is recorded at each critical control point	(10) *Record the procedure used to remove plant fragments. Record that inspections occurred prior to leaving one lake and before entering the next lake.*	*Record the procedure used to remove zooplankton. Record that inspections occurred prior to leaving one lake and before entering the next lake.*

This form accomodates 2 Critical Control points. Attach additional pages of this form as necessary.

Final Step:

Once the HACCP plan is completed, attach it to the signed procedure form with the hazard analysis worksheets

AIS-HACCP PLAN

Aquatic Invasive Species - Hazard Analysis and Critical Control Point **AIS-HACCP Plan Form**

Critical Control Point Each row answered "yes" in column 6 of Hazard Analysis Form	**(1)** *Day 3, trailer boat and electric motor to Little Beaver L., cross Little Beaver L. into Beaver L., cross Beaver L. and beach at trail to Trappers L. Portage inflatable boat to Trappers L., conduct sampling, deflate boat, and return to Beaver L*	*Day 3, trailer boat and electric motor to Little Beaver L., cross Little Beaver L. into Beaver L., cross Beaver L. and beach at trail to Trappers L. Portage inflatable boat to Trappers L., conduct sampling, deflate boat, and return to Beaver L*
Significant Hazards as determined in column 3 of Hazard Analysis Form	***(2)*** *Bythotrephes could be stuck to waders used in Beaver L.*	*The presence of plant AIS in all lakes is unknown. If present, species could be transported from an infested lake to an uninfested lake. This step serves for all plant AIS in following steps.*
Limits for Each Control Measure	***(3)*** *Do not use waders at Trappers L., use equipment on Trappers L. before using on Beaver L.*	*No viable plant parts remain on canoe/boat, trailer, or other equipment.*
Monitoring Describe what is being monitored	***(4)*** *Ensure equipment is used on Trappers L. first and waders from Beaver are not used on Trappers.*	*Presence of exotic plant material. Ensure that canoe/boat and all equipment are free of viable plant parts.*
Explain how the monitoring will take place	***(5)*** *Verbal check between sampling staff.*	*Visual inspection of canoe/boat, trailer, and other equipment for plant fragments.*
Frequency of monitoring	***(6)*** *Each time Trappers L. is sampled.*	*Each time, before and after equipment is used in a lake.*
Person or position responsible for monitoring	***(7)*** *Water quality monitoring staff.*	*Water quality monitoring staff.*
Corrective Actions Actions taken when limits of control measures are not met	***(8)*** *Clean equipment with water from Trappers L. before using it in lake. Visually inspect equipment.*	*Cease operation and clean equipment before launching onto water.*
Verification Method of verification	***(9)*** *Review records.*	*Review records.*
Records List what is recorded at each critical control point	*(10) Record the sampling sequence and whether corrective actions were taken.*	*Record the procedure used to remove plant fragments. Record that inspections occurred prior to leaving one lake and before entering the next lake.*

This form accomodates 2 Critical Control points. Attach additional pages of this form as necessary.

Final Step:

Once the HACCP plan is completed, attach it to the signed procedure form with the hazard analysis worksheets

AIS-HACCP PLAN

Aquatic Invasive Species - Hazard Analysis and Critical Control Point **AIS-HACCP Plan Form**

Critical Control Point Each row answered "yes" in column 6 of Hazard Analysis Form	**(1)** *Day 3, continued: Motor to site on Little Beaver L. and conduct sampling. Trailer boat and electric motor back to maintenance bldg.*	
Significant Hazards as determined in column 3 of Hazard Analysis Form	***(2)*** *Sampling equipment and anchor rope could have Bythotrephes stuck, which could get be transported to another lake.*	
Limits for Each Control Measure	***(3)*** *No viable zooplankton remain on equipment, including anchor rope.*	
Monitoring Describe what is being monitored	***(4)*** *Presence of exotic zooplankton. Ensure that all equipment is free from zooplankton.*	
Explain how the monitoring will take place	***(5)*** *Visual inspection of equipment for zooplankton.*	
Frequency of monitoring	***(6)*** *Each time, after equipment is used in Beaver or Little Beaver Lakes.*	
Person or position responsible for monitoring	***(7)*** *Water quality monitoring staff.*	
Corrective Actions Actions taken when limits of control measures are not met	***(8)*** *Clean equipment again, and inspect again.*	
Verification Method of verification	***(9)*** *Review records.*	
Records List what is recorded at each critical control point	*(10) Record the procedure used to remove zooplankton. Record that inspections occurred prior to leaving one lake and before entering the next lake.*	

This form accomodates 2 Critical Control points. Attach additional pages of this form as necessary.

Final Step:

Once the HACCP plan is completed, attach it to the signed procedure form with the hazard analysis worksheets

Standard Operating Procedure #6:
Field Measurements and Water Sample Collection

Version 1.0

In **Water Quality Monitoring Protocol for Inland Lakes**

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Revision History Log

The following table lists all edits and amendments to this document since the original publication date. Information entered in the log must be complete and concise. Users of this standard operating procedure will promptly notify the project manager and/or the Great Lakes Network (GLKN) data manager about recommended and required changes. The project manager must review and incorporate all changes, complete the revision history log, and change the date and version number on the title page and in the header of the document file. For complete instructions, please refer to Revising the Protocol, SOP #13.

Revision History Log:

Previous Version #	Revision Date	Author (with title and affiliation)	Location in Document and Concise Description of Revision	Reason for Change	New Version #
Add rows as needed for each change or set of changes tied to an updated version number					

Acknowledgements

Combinations of existing protocols were used to develop this standard operating procedure for measuring the required water quality field parameters for the Great Lakes Network (GLKN). We consulted protocols written for the EPA (Baker et al. 1997), USGS (Hoffman et al. 2005, USGS 2005), and this and other NPS networks (Magdalene et al. 2007; O'Ney 2005); an on-line curriculum for monitoring water quality (WOW 2004); and NPS internal documents (Irwin 2006, 2004; Penoyer 2003; and the WRD website [http://www.nature.nps.gov/water/vitalsignsguidance.cfm]). We wish to acknowledge these sources and thank them for the valuable contribution that they have made to this document.

6.0 Introduction

Field measurements should represent, as closely as possible, the natural condition of the surface water at the time of sampling. Experience with and knowledge of the sampling equipment and the collection, storage, and processing of water samples for subsequent laboratory analyses are critical for collecting data of high quality. To ensure consistent, high-quality data, always:

- Make field measurements only with calibrated instruments that have been error-checked.
- Maintain a permanent log book for each field instrument for recording calibrations and repairs. Review the log book before leaving for the field.
- Test each instrument (meters and sensors) before leaving for the field. Become familiar with new instruments and new measurement techniques before collecting data.
- Have backup instruments readily available and in good working condition.
- Follow quality assurance/quality control procedures in SOP #12. Such protocols are mandatory for every data collection effort, and include practicing good field procedures and implementing quality-control checks. Make field measurements in a manner that minimizes artifacts that can bias the result. Check field-measurement precision and accuracy (variability and bias).

6.0.1 Core Suite of Water Quality Variables

The core field variables are temperature, specific conductance, pH, water level, and dissolved oxygen, all of which are mandated by the National Park Service Water Resources Division (NPS-WRD). To this mandated suite, GLKN has added a measure of water clarity. Depth profiles of temperature, specific conductance, pH, and dissolved oxygen will be measured at each sampling station using a multiparameter instrument (multiprobe). Water level will be measured at benchmark stations with an eye or laser level and a surveyor's rod (described in detail in SOP #4). Water clarity will be measured with a transparency tube or Secchi disk. The expected ranges and resolutions required of multiprobes are listed in Table 1, and the methods for taking field measurements are described in Section 6.4.

6.0.2 Advanced Suite of Water Quality Variables

The advanced suite variables consist of total phosphorus, total nitrogen, nitrate+nitrite-nitrogen, ammonia-nitrogen, sulfate, chloride, magnesium, calcium, potassium, sodium, dissolved silica, total organic carbon, alkalinity, and total chlorophyll-*a*. The methods for collecting water samples for these variables are described in Section 6.5. These water quality variables were chosen to monitor effects of the likely stressors on the resource, including land use change and atmospheric deposition. Other variables symptomatic of contamination (e.g., DDT and PCBs) are addressed in GLKN's protocol for monitoring bioaccumulative contaminants (Route et al., in preparation).

6.1 Equipment and Supplies

6.1.1 Instrument Specifications

Toward low bias and high precision of water quality data for this protocol, Table 1 lists typical field sensor performance specifications that should be expected from monitoring equipment for this protocol. Multiparameter sensor instruments (or multiprobes), while expensive, are convenient and commonly used in water quality monitoring. A multiprobe instrument should be selected based on the observable range for each variable. However, an additional investment in a back-up set of less expensive individual sensors will help ensure the development of a long-term data set, should the multiprobe not be working properly.

Table 1. Typical sensor performance specifications[a] for field instruments (Penoyer 2003).

Sensor	Expected Range	Reporting Resolution [b]	Estimated Bias [c]
Temperature	-5 to 45 °C	0.01 °C	±0.15 °C
Specific Conductivity (SC25)	0 to 2000 uS/cm	1 uS/cm (range dependent)	±0.5% of reading + 1 S/cm
pH	1 to 14 units	0.01 unit	±0.2 units
Dissolved Oxygen (Concentration)	0 to 50 mg/L	0.01 mg/L	0 to 20 mg/L; ±0.2 mg/L; 20 to 50 mg/L:±0.6 mg/L
Dissolved Oxygen (% saturation)	0-200%	0.1%	~ ±2 %
Turbidity	___	____	_____
Depth - Z (pressure sensor)	0 - > 100m	0.1 m	~ 0.1 m

Notes:
a: In the case of field probes, accuracy is typically a best-case maximum deviation from known correct values (typically based on comparisons with known NIST certified reference materials or standards).
True accuracy is a combination of high precision and low bias (see Irwin 2004 for more details).
b: Resolution/sensitivity is a data quality indicator related to detection limits but typically handled differently for field probes than for laboratory parameters. For more information, see Irwin (2004).
c: Estimated bias specifications reflect the uncertainty in measurement of the instrument and sensor in combination only, and not other factors that can affect accuracy, such as environmental variables or the ability of field personnel to calibrate and operate the instrument using proper protocols.

Instrument-specific estimations of the range of uncertainty for each variable must be calculated for use in the interpretation of data. Therefore documentation will be maintained regarding the ability of each multiprobe to meet the data quality objectives of this project; blank forms are included in SOP #12. The completed forms for each multiprobe will be maintained along with the calibration and maintenance logs for the multiprobe.

Details on estimating instrument sensitivity are included in SOP #12, Quality Assurance/Quality Control. Because field equipment is likely to change during the course of this long-term monitoring project, QA/QC procedures must be followed on documenting cumulative bias (SOP #12).

6.1.2 Additional Equipment, Supplies, Forms, etc.

Refer to the checklist of supplies and equipment needed for field sampling (Table 2) prior to each sampling trip. Keep on hand all necessary forms, calibration logbooks, field logbooks, field data sheets, procedural manuals, and equipment instructional manuals.

Table 2. Checklist of field equipment and supplies required for monitoring water quality.

√	Equipment and Supplies
	Field notebook, pencils, and pen (waterproof ink)
	New field forms on waterproof paper
	Up-to-date field folders containing recent data sheets for field comparison (copies only; never take originals in the field)
	Multiparameter instrument (calibrated), calibration standards, check solutions, data logger
	Long and short cables for multiprobe instrument(s)
	Calibration logbook for each instrument
	All maintenance parts and calibration standards for field instruments
	Backup instruments in case of electronic failure of multiprobe (for example: YSI 85 [T-DO-SC25] or equivalent, YSI 200 [T-DO], Hannah Dist3 [SC25], armored NIST certified thermometer [°C], portable pH meter)
	Transparency tube
	Secchi disk and metered line (marked at 0.5 m intervals)
	Sounding weight(s)
	Surveyor's rod and level
	Water samplers: Integrating tube, Van Dorn type sampler
	Compositing jug and other bottles
	Weather radio or barometer
	Pocket calculator (waterproof, if possible)
	Extra batteries for all field equipment (multiparameter probe, calculator, GPS, etc.)
	Rain gear
	Personal flotation device(s)
	Field trip itinerary
	Cellular phone and/or park radio
	Digital camera with extra flash cards and battery
	Map(s) of station location, preferably at different scales
	Global positioning system (GPS)
	Deionized or distilled water for field rinsing

Copy field data sheets on waterproof paper. See the attachments for blank data sheets. The instruction manuals for each instrument should be copied and the originals placed in a secure file

and kept in the office. Specific sections of the manual that might be important to have in the field should be copied onto waterproof paper and remain in the field kit.
Include copies of a datalogger software manual.

6.2 Overview of Field Work

6.2.1 Sequence of Activities During Field Workday

1. Review field gear checklist.
2. Create a new field form for each monitoring station, printed on waterproof paper.
3. Prepare sample bottles and labels in advance and place in a cooler.
4. Conduct daily calibration of appropriate meters and probes.
5. Inspect vehicles at the beginning of every field day, including all safety and directional lights, oil, gasoline, tire air pressure levels.
6. Inspect boat; ensure all safety gear is on board.
7. Drive to boat landing. Load boat with sampling gear, launch boat, and navigate to monitoring site. Set up a clean work space on the boat for sampling.
8. Refer to description of monitoring station location, directions, maps, and photo to verify correct location. Verify coordinates on GPS unit.
9. Measure field water quality variables per Section 6.4 and collect samples per Section 6.5.
10. Be sure that all samples are correctly labeled and preserved on ice.
11. Clean sampling equipment per SOP #7. Rinse sensors with deionized water and perform calibration re-checks, as detailed in SOP #12.
12. Record measurements of water level as detailed in SOP #4.
13. Verify that field form is completely filled out, and initial the form.
14. If sampling from more than one monitoring station in a day, follow procedures for decontamination of equipment per SOP #5, and go back to step 6, above.
15. Upon return to shore, inspect boat, trailer, and all equipment that has come into contact with the water for invasive species.
16. Return to office or field station.
17. Process samples according to SOP #7. Refrigerate or freeze samples, as required and package samples for sending to contract analytical laboratory.
18. Enter field and laboratory data into NPSTORET as soon as possible after receiving and reviewing data.

6.2.2 Recording Field Information Upon Arrival at Monitoring Site

Consistent methods are important to long-term data quality. In actuality, the ideal conditions are not always met in the field or in the lab and changes in staff occur. Therefore, documentation of procedures, site conditions, laboratory analysis, and reasons for deviations of any kind is important. Personnel are encouraged to write down more than they feel may be necessary in the moment, as the future interpretation of their data will depend on the written record and not the memory of an individual. Waterproof field forms (copy available in the attachments) should be prepared ahead of time labeled with the project and station IDs. Sampling stations will be identified by park and water body name according to GLKN guidance. Information on the sampling station and park will comply with NPSTORET requirements. Field sampling forms are

used to record the physical and chemical water quality variables measured at the time of sample collection. In addition to recording the field variables, any samples collected for laboratory analyses must be so indicated. Documentation should include calibration data for each instrument, field conditions at the time of sample collection, visual observations, and other information that might prove useful in interpreting these data in the future.

While at each monitoring site, the information recorded on field sampling forms should include:

- Date
- Time of arrival
- Names of field team members
- GPS coordinates, to verify location
- Current weather (air temperature and wind speed) and relevant notes about recent weather (storms or drought), including days since last significant precipitation
- Observations of water quality conditions (see below)
- Multiparameter meter (model/serial no.), calibration date, and field measurements of core suite variables
- List of sample IDs and collection times for advanced suite variables or quality assurance samples
- Whether any samples were not collected, and reason
- Quality assurance/quality control procedures followed
- Water level measurement
- Any other required metadata for NPSTORET data entry
- Time of departure

All entries should be made clearly. If an incorrect entry is made, a single heavy line should be drawn through the incorrect entry and the correction made. All corrections should be initialed and dated. The completed field forms will be maintained in chronological order by station, copied into project binders and the originals maintained on file indefinitely. Field data are reviewed annually by GLKN personnel (see SOP #8, Data Entry and Management, for details).

Upon arrival at the monitoring station, record visual observations of water quality conditions that will be useful in interpreting water quality data.

- Water appearance — General observations on water may include color, unusual amount of suspended matter, debris, or foam.
- Biological activity — Excessive macrophyte, phytoplankton, or periphyton growth. The observation of water color and excessive algal growth is important in explaining high chlorophyll-*a* values. Other observations to note include types of fish, birds, or spawning fish.
- Unusual odors — Examples include hydrogen sulfide, mustiness, sewage, petroleum, chemicals, or chlorine.
- Watershed activities — Activities or events that are impacting water quality; for example, road construction, timber harvest, shoreline mowing, or livestock watering.

6.2.3 Preventing Contamination

Field technicians should be aware of and record potential sources of contamination at each field site. Decontaminate field sampling equipment according to SOP #5 for minimizing the risk of spreading invasive species. Clean field and laboratory equipment according to SOP #7 to avoid contamination of analytes to be measured. Do not allow sample water to touch hands; do not touch insides of sampling equipment, containers, or laboratory bottles.

6.2.4 Using Disposable Gloves

Wearing disposable gloves is strongly recommended when handling acid preservatives. Check manufacturer's chemical resistance information to be sure gloves are appropriate for compounds to which they will be exposed. Common glove types include those made of vinyl, latex and nitrile; nitrile is in standard use for USGS sampling work because of its resistance to most of the chemicals to which it typically will be exposed for the length of exposure (usually < 15 minutes). Field personnel are cautioned that direct contact with materials such as latex or nitrile can cause severe allergic reactions in some individuals and should be monitored.

Physical properties to consider when selecting disposable gloves are glove length, slip protection, puncture resistance, heat and flame resistance, cold protection and comfort. These factors can vary between manufacturers. Gloves should be inspected visually for defects. Check for tears, punctures and other flaws that can prevent the glove from being an effective shield. After putting the gloves on, rinse them with water while gently rubbing hands together to remove any surface residue before handling sampling equipment.

6.2.5 Bottle Preparation – Types and Sizes of Bottles

For each monitoring station, select the bottles appropriate for each analyte and label them with Station ID, sample date, and analyte code according to the requirements of the contact analytical laboratory. Store pre-labeled bottles in a dry box or in separate bags for each station.

6.3 Field Measurement Procedures

6.3.1 Where and When to Measure Field Variables

The deepest part of the lake is the preferred sampling site. If the morphometry is not known, sample at the estimated geographic center unless there is another basis for selecting the site.

Routine monitoring will occur three times throughout the open-water season, typically from May through October, with more narrowly-defined sampling windows depending of a park's latitude. All three sampling periods should occur when lakes are stratified. It is extremely difficult to predict either spring or fall turnover, although the spring period immediately follows ice-out. Fall turnover, in the sense of a period when the temperature is uniform, and more importantly, when DO is uniformly 100% saturated, is much less predictable. It also occurs at a more dangerous time of year to be on the water (November to December). May through October will provide ample sampling dates to be able to fully characterize the major period of plant growth, oxygen

depletion, water clarity, temperature change, maximum public use, and the variable periods of algal nuisance blooms.

Sampling should be conducted during mid-day, from 10:00 AM to 3:00 PM, when possible. Water samples and Secchi depth readings are typically collected during mid-day to reduce variability in the data due to the differences in daylight, and to a lesser extent, temperature (Carlson and Simpson 1996). Mid-day is usually the peak period of algal photosynthesis, which can have dramatic effects on DO, transparency, and dissolved inorganic phosphorus (phosphate) and dissolved inorganic nitrogen (nitrite+nitrate+ammonium) throughout a 24 hr cycle.

For all sampling, it is critical to avoid sampling water showing evidence of oil, gasoline or anything else from the boat motor. It is best to turn off the engine and set the anchor, although this may not be possible or advisable in bad weather or with a balky engine. The engine is commonly located in the stern of the boat; therefore, the anchor should be secured near the prow of the boat, such that strong winds will rotate the stern to the downwind. After setting anchor, allow surface water to clear of disturbances. Collect samples on the upwind side of the boat, to minimize contamination and disturbance. Avoid surfactants, floating debris, and turbid aeration during sample collection. Discard rinse water or excess sampling water on the downwind side of the boat.

6.3.2 Stabilization of Sensor Probe Readings

Before making field measurements, properly-calibrated sensors must be allowed to equilibrate to the condition of the water being monitored. Sensors have equilibrated adequately when instrument readings have stabilized, that is, when the variability among measurements does not exceed an established criterion. The criteria for stabilized field readings were defined by O'Ney (2005) for a set of three or more sequential measurements (Table 3). Although the criteria used by the Greater Yellowstone Network (O'Ney 2005) differ from those used in the upper Midwest by the NRRI-UMD group (WOW 2004), the differences are small in comparison to the true range of variability one might expect in the field and with aging instrument sensors. The natural variability inherent in surface water or ground water at the time of sampling generally falls within these stability criteria and reflects the accuracy that should be attainable with a calibrated instrument. In the case of field probes, accuracy is typically a best case maximum deviation from known correct values (typically based on comparisons with known NIST certified reference materials or standards). True accuracy is a combination of high precision and low bias (see Irwin 2006, 2004 for more details).

Dissolved oxygen typically requires the greatest amount of time to stabilize. In addition, differences in polarigraphic sensor membrane thicknesses, age, and rates of oxygen consumption increase the variability of the equilibration time. The longest equilibration times will typically occur where dissolved oxygen exhibits a steep gradient (change in DO concentration > 5 mg/L) or very low oxic levels (DO concentration < 3 mg/L). Depending on the site characteristics and the specific oxygen sensor, 3 to 5 minutes may be required for complete equilibration. This time far exceeds what is needed for the other variables, which typically stabilize in less than 60 seconds. Observers should only note instrument DO readings after the stabilization criteria in Table 3 are met, and then record readings for all variables at once.

Table 3. Recommended instrument stabilization criteria for recording field measurements.

Standard Direct Field Measurement	Stabilization Criteria (O'Ney 2005)	Stabilization Criteria *In situ* Multisensors (WOW 2005)
Temperature: Thermistor Thermometer Liquid-in-glass Thermometer	± 0.2 °C ± 0.5 °C	± 0.2 °C (5%)
Specific Conductivity (SC25) When ≤ 100 µS/cm When > 100 µS/cm	± 5 % ± 3 %	< 5 uS/cm (10%)
pH: Meter displays to 0.01	± 0.1 unit	± 0.2 unit (10%)
Dissolved oxygen: Amperometric (same as polarigraphic) method	± 0.3 mg/L ± 2%	± 0.5 mg/L (10%)

6.3.3 Outline of Water Profile Measurements

Acquiring high quality results requires the use of consistent measurement methods. Adhere to the following guidelines:

1. Depths ≤ 20 m: Measure T, DO, pH, and SC25 surface to bottom at 1 m intervals.

2. Depths >20 m: Decrease measurements to 2 m intervals down to 30 m and to as much as 5 m increments for greater depths.

3. Wait for the DO value to stabilize first, record the value, then read the other parameters. Because DO takes the longest to stabilize this assures all parameters have equilibrated. See section 6.4.4 for further details. Stabilization of the DO value will typically take anywhere from 30 seconds to several minutes, depending on the gradient from the previous depth and the age and type of oxygen membrane or probe. Extra time should be allowed for equilibration when values are below approximately 3 mg/L. If the sonde does not have a stirring mechanism, jiggle the cable gently approximately once per second.

4. Enter all data on field forms.

5. Quality Assurance (QA): At a minimum, replicate one of every 10 sets of measurements (e.g., at 1 m, 10 m, etc.). The replicate should be taken immediately following the original reading. Values should agree within ± 10% or the detection limits listed in Table 3, whichever is larger.

Instrument problems or failure

- If water quality sensor measurements are not representative of field conditions based on previous data or limnological knowledge, re-calibrate and try again.

- If readings seem reasonable, proceed. If not, first check the troubleshooting guide in the instrument manual. If problem persists, collect as much data as possible using back-up hand held instruments, if available. Using the Van Dorn bottle, collect a sample from 2.5, 5, 7.5, and 10 m, and then at 5 m intervals to the bottom, and record values obtained by dipping the sensors into the top of the sampler. In the case of measuring DO, jiggle the probe without causing bubbles to form in low DO hypolimnetic samples. If, after approximately 2 min, the value continues to decrease, increase the rate of swirling or jiggling to see if it will stabilize; if it is increasing after 2 minutes, you may be agitating the water enough to be causing an aeration artifact near the surface. If too much time elapses and the temperature of the water sample has increased by more than 1 ^{o}C, collect a fresh sample.

6.3.4 Detailed Description and Troubleshooting Hints for Field Variables

Because temperature, DO, and other water quality variables are important determinants of biotic habitats, it is important that observers write down values on field forms and think about their ecological meaning, even if a data logger is recording the measurements. The hard copy also serves as backup in case there is an electronic failure.

6.3.4.1 Temperature

Temperature (T) is measured in units of degrees Celsius (°C) and recorded to the nearest degree or tenth of a degree as warranted by instrument.

1. If a cabled thermistor is not available, the high specific heat of water allows a temperature profile to be obtained by bringing deep samples to the surface with a water sampler and immediately measuring temperature with a hand-held thermometer or thermister. Anything immersed into the water sampler potentially contaminates that particular sample; a separate sample must be collected for water chemistry.

2. The upper few centimeters of soft sediments are often several tenths of a degree warmer than the overlying water. The rise in temperature can be an indication that the probe is submersed into the sediments. If this happens, be sure to vigorously shake the instrument in shallow water with high DO to clean it before re-taking measurements. Check intermediate depth values, and if these values do not meet QA criteria, pull the instrument to the surface and clean it.

6.3.4.2 Specific Conductivity

Specific conductivity (SC) is the ability of water to conduct an electrical current for a unit length and unit cross-section at a certain temperature, measured in units of microsiemens per centimeter (µS/cm), and recorded to the nearest µS/cm. Commonly used in water quality monitoring, SC is a general measure of the number of ions dissolved in the water. It is important to be aware of the difference between SC (specific conductivity at the ambient temperature of the sensor) and SC25 (an abbreviation for specific conductivity temperature compensated to 25°C). This difference becomes very important in profiling stratified lakes where the hypolimnion is cold with respect to the epilimnion. In such cases, the typical increase in ions with depth, as estimated by SC25, would be substantially offset by the corresponding decrease in SC due to decreasing temperature.

The difference between SC and SC25 can confound analyses of seasonal patterns of dissolved ions since water temperatures vary throughout the year. The SC25 can be used to monitor seasonal changes in total dissolved salts (TDS) such as a spring flush of road salt, which is why the temperature compensation is so important. Many instruments will display SC in addition to SC25. In the event that an uncompensated sensor must be used (older instruments and most pocket conductivity meters are not temperature-compensated), the value of SC25 can be calculated from SC and temperature values (see # 3 below). The value of SC should be recorded on the field form even when SC25 will be calculated.

1. A common physical problem in using a specific conductance probe (or meter) is entrapment of air in the conductivity probe chambers. Its presence is indicated by unstable specific conductance values fluctuating up to $\pm$ 100 µS/cm. This problem is much more prevalent in turbulent stream waters and can be minimized by slowly and carefully placing the probe vertically into the water and when completely submerged, quickly moving it back and forth through the water to release any air bubbles. An SC probe with an open flow design does not trap air.

2. Is the value real or is the instrument out of calibration? Having specific conductance standards in the field can help verify values that fall outside the expected range. For example, the expected specific conductivity is around 200 and the reading is 1500. A known standard can be put in the instrument storage cup to determine if the instrument is reading correctly or is out of calibration.

3. SC25 values can be calculated from uncompensated SC values via a temperature-compensation formula. For example, for YSI probes, use:

$$SC_{25} = \frac{SC_m}{1 + 0.0191 \cdot (t_m - 25)}$$

Where, SC_{25} = corrected conductivity value adjusted to 25°C,
SC_m = measured conductivity before correction; and,
t_m = water temperature at time of SC_m measurement.

Contact the instrument vendor for the appropriate formula.

6.3.4.3 Hydrogen Ion Activity (pH)

Commonly used in water quality monitoring, pH is a measure of the acidity of water, measured in standard pH units (SU), and recorded to the nearest 0.1 pH unit. The pH scale is from 1 to 14: neutral water is pH 7, acidic waters have pH <7, and alkaline waters have pH >7.

- Is the value real or is the instrument out of calibration? Having pH standards in the field can help verify values that fall outside the expected range. For example, the expected pH is around 7.0 and the reading is 9.5. A known standard can be put in the instrument storage cup to determine if the instrument is reading correctly or out of calibration.

- As with dissolved oxygen, a pH probe can take longer to equilibrate when the gradient from the previous measurement is large (>1.0 pH SU).

- Low ionic strength waters with SC25 < 50 µS/cm can cause pH measurement stability problems with some probes, necessitating use of low ionic strength probes. Probes will often calibrate fine in strong ionic strength buffers but will not read accurately in lower ionic strength surface waters. If you suspect this is the case, use a sensor that is designed for low ionic strength waters.

- Because the pH scale is logarithmic, field values may first have to be converted to hydrogen ion activity (i.e., concentration) values, averaged, and re-transformed to pH standard units prior to conducting statistical analysis. To compute a mean pH for a group of data:
    - Convert each pH value to hydrogen-ion activity, using the equation: Hydrogen Activity = 10^{-pH}.
    - Calculate the mean of the activity values by adding the values and dividing the sum by the total number of values.
    - Convert the calculated mean activity back to pH units, using the equation, pH = - $\log_{10}$ (mean hydrogen activity).

6.3.4.4 Dissolved Oxygen

Dissolved Oxygen (DO): units of mg/L record value to nearest 0.1 mg/L unless otherwise justified; percent saturation (% DO) record value to nearest %; also temperature compensated to 25°C.

- Be aware that if a water sample has a strong rotten egg smell (H_2S gas) it must have a DO of zero. This is one way to check your meter. You can use the measured offset value to correct your higher DO values. Do not report negative DO values in the final database although it is important to report them on the field data sheet. Do the correction afterwards but note on the field sheet the depth at which you could smell sulfide gas. Avoid touching the bottom, if possible, as the membrane may become fouled.

- Equilibration time is critical; the steeper the DO gradient, the longer the equilibration time. It may take >5 minutes when DO drops abruptly to near zero.

- The DO probes with membranes actually consume oxygen in the immediate vicinity around the membrane as they work; measurements therefore require moving water using either a built-in stirrer (typical in multiparameter sondes and BOD probes) or moving the cable up and down (e.g., 6”each side of the desired depth) during the measurement. Optical sensors do not consume oxygen and hence do not require moving water.

- If the electronic DO meter is not functioning properly, DO can be measured by Winkler titration (APHA 1998). A variety of field kits are convenient and cost effective, including Lamotte, Hach, and others.

6.3.4.6 Clarity

Measurement of Secchi disk transparency has historically been the most common means of measuring water clarity due to its simplicity. It is a qualitative evaluation of the transparency of water to light based on the reflection of light from the surface of the Secchi disk and is a function of the absorption characteristics both of the water and its dissolved and particulate matter. To get an accurate measure of Secchi depth, the disk must hang vertically from the side of the boat. The transparency tube, which uses the same principle as a Secchi disk, is recommended when the Secchi disk can be seen on the lake bottom or when the disk does not hang vertically due to a current or an unstable boat.

6.3.4.6.1 Secchi Depth:

1. Measure Secchi depth using a 20 cm (8 in diameter) black and white Secchi disk from the shaded side of the boat. Do not wear sunglasses while viewing the Secchi disk.

2. Measurements should be made as near to midday as possible (10 AM to 3 PM; sunny and calm is optimal). Visit each lake as close to the same time of day as previous visits in order to minimize diurnal variation.

3. Try to lower the disk in the shade of the boat and make sure that the line is hanging vertically. In strong currents or choppy waves, it may be helpful to tape a rock or weight to the bottom of the disk.

4. Slowly lower the disk into the water until it disappears and note the depth.

5. Lower the disk a little farther, then slowly raise it until the disk reappears and note the depth again.

6. Average the two readings and record the value. Record the Secchi observer on the data sheet (see #8 below).

7. Record the conditions present when the Secchi measurement was made, with 1 being excellent (sunny clear skies, calm water), 2 being moderate (some clouds, small waves), or 3 being poor (dark skies, very choppy water, or currents that make it extremely difficult to read).

8. Quality Assurance (QA): At a minimum, replicate Secchi readings at every tenth site. Because of the apparent ease of this measurement yet its potential difficulty in less than ideal conditions, all field crew members should take this measurement at each site for at least the first round of sampling The crew should not reveal their value until all are finished and then all values should be recorded and compared. Values should agree within $\pm$ 10% for Secchi measurements <5 m and $\pm$ 0.5 m for greater values.

6.3.4.6.2 Transparency Tube:

1. Measure transparency tube clarity using a 120 cm tube if the Secchi is visible on the bottom of a lake or wetland pond. For all shallow (< 2 m) lakes and ponds, measure

clarity with a transparency tube even if Secchi measurements can be made on occasion because clear water times can occur, when Secchi depth cannot be measured.

2. The tube should be set on a white towel background, shaded by your body, and read without sunglasses.

3. Water should be dispensed from a carboy that was used for integrating water samples (see below) rather than dipped from the water body. The carboy must be well shaken prior to filling the tube to minimize artifacts due to settling of sand and larger silt particles. Allow air bubbles to disappear before making the final measurement.

4. While slowly releasing water from the bottom of the tube via its valve, note and record the depth at which the mini-Secchi first becomes visible. Discard the remaining water and repeat the measurement with a second subsample from the carboy.

5. Several attempts to read the clarity may be necessary because of overshooting the endpoint, so collect plenty of water for this analysis. A standard 120 cm x 4.5cm outside diameter tube requires approximately1.5 L to fill it, so dedicate at least 4 L of water for this measurement.

6. During clear water periods, the tube may not be long enough for a measurement. In such cases, the value should be recorded as >120 cm. If it appears to be barely visible, this fact should be recorded to distinguish it from a measurement where it is clearly visible.

7. Quality Assurance (QA): At a minimum, replicate transparency tube readings at every tenth site. As for the Secchi reading, because of the apparent ease of this measurement yet its potential difficulty in less than ideal conditions, all field crew members should take this measurement at each site for at least the first round of sampling. Crew members should not reveal their values until all are finished and then all values should be recorded and compared. Values should agree within 10%. This acceptance criterion is subject to change as more data from various volunteer monitoring programs become available (such as the Minnesota Citizen Stream Monitoring Program (http://www.pca.state.mn.us/water/csmp.html).

<u>Maintenance notes and other precautions:</u>

1. The rubber stopper (with attached Secchi) can be dislodged easily. Tape the stopper with black vinyl electricians tape and carry an extra stopper-Secchi.

2. Clean the transparency tube periodically with mild dish soap and a soft cloth.

3. Although water from the tube may be saved for turbidity and TSS measurements, do not save it for nutrient or other pollutant analyses because the tubes are not cleaned according to certified protocols.

4. Subsampling and settling issues are important, as particles settle quickly. A stopper for the top of the tube is useful to allow for resuspension during the measurement if rapid

settling occurs.

5. Dissolved color due to organic matter (humic and fulvic acids, usually from bogs and conifer needles) can confound comparisons of transparency tube data between lakes. Also, lakes with similar concentrations of suspended sediments can have different transparency because smaller particles scatter more light.

6. A transparency reading taken from one tube can not be compared with a reading taken from another tube made by a different manufacturer if the dimensions are different.

6.3.5 Measuring Water Level

Water level will be measured relative to a benchmark or reference mark. GLKN will always install markers above water level, but extreme water level fluctuations could submerge a marker that was originally well above the ordinary high water mark. In some cases, benchmarks may have been installed by other agencies, and may not be above current water level. Water levels that are below the reference marker will be recorded as negative numbers; levels above the marker will be positive.

A single person can measure water level above a reference mark by placing a measuring device, such as a meter stick, on the marker and reading the water level directly on the device. Two people are required to measure water level when the reference marker is above the current water level. One person holds a stadia rod at the water's edge, while the second person uses an eye level or laser level at the benchmark to view the stadia rod.

Detailed instructions for installing reference markers and measuring water levels can be found in SOP #4, Measuring Water Level.

6.4 Water Sample Collection

A tube sampler collects and integrates a column of water into a single sample. If the top end is capped, all or most of the water will remain in the tube as it is raised. The main advantage over using a surface dip (often called a grab sample), is that a larger stratum of water in the epilimnion is represented by the sample, reducing the effect of high chlorophyll concentrations from concentrated scums on the seasonal mean. Bottom water, and on occasion other depths, will be sampled using a Van Dorn or Niskin type remote-closing water bottle. Although less durable, a transparent acrylic bottle allows the crew to ensure that near bottom water samples do not contain suspended bottom sediment before pouring the (contaminated) water into the sample bottles. Precautions will be taken to check with the manufacturer regarding the potential for nutrient or other contamination from the sampler. Before its first use, the sampler will be cleaned thoroughly by rinsing three times with hot tap water, rinsing three times with 0.1 N HCl, and finally, rinsing three times with deionized water.

6.4.1 Integrated Sampling Tube

1. Rinse compositing jug 3 times before sampling. Increase surface water flushing to 6

rinses if the compositing jug previously contained water that was contaminated with sediment or water deemed to have much higher nutrient levels.

2. Remove both stoppers from integrated sampler. Rinse the integrated sampler in lake water 3 times (lower to 2 m, raise, lower again, etc. for 3 rinses).

3. Collect sample by lowering sampler into water column (if water depth will allow it). If the site is too shallow for the 2 m sampler, then use one of the following methods:

    - collect sample by using the integrated sampler on an angle instead of vertically,
    - fill jug with 0.5 m deep water using the Van Dorn/Niskin sampler,
    - or fill jug via surface grab.

    Secure the top stopper, raise the sampler vertically, and immediately drain it into the rinsed compositing jug. The sampler will start releasing its water as soon as it clears the water surface. Two or three integrated samplers of water will be needed to fill a 6 L jug. Fill the jug at least 75% full to ensure adequate water for all analyses; if a transparency tube measurement will be done, an entire jug is needed. Extra water simply reduces variance associated with the site.

4. Once water is collected, immediately begin dispensing it into appropriate analyte bottles or keep jug cold and dark until processing in the park lab or home base at the end of the day (details below).

6.4.2 Discrete Depth Sampling

During the mid-summer sampling when the lake is thermally stratified, (defined as a gradient of ≥ 1 °C/m or DO levels ≤ 2 mgO_2/L), collect two separate samples.

Collect surface water with the 0 - 2 m integrated tube sampler as above; collect bottom water with Van Dorn or Nisken sampler from approximately 0.5 to 1 m above the lake bottom. Because the hypolimnetic water will be used for nutrient analyses only, a smaller container (1 or 2 L) may be used for storage and transport to the sample processing site.

6.4.3 Distributing Sample Water from the Compositing Jugs

- Always ensure composite water is well mixed prior to dispensing it to any other containers.
- Rinse bottles and caps for chlorophyll-*a* with lake water 3 times, prior to filling. Uncap and re-cap bottles below water surface to avoid surface scum or debris.
- Fill dark plastic bottle for chlorophyll-*a* (at least 1 L); keep cold and dark until filtering at the end of the day.

If the water sample is processed on-site, follow the instructions below, in addition to those in SOP #7.

Integrated 0 - 2 m Water

1. Rinse caps and bottles with composit water 3 times, using approximately 50 mL for each rinse, prior to filling. Shake out excess water.

2. Cap and re-agitate composite jug and then dispense water into previously labeled appropriate bottles. Be careful not to overfill bottles pre-loaded with acid. Fill nutrient bottle to the neck of the bottle – this will prevent the bottle from breaking when the water expands as it freezes.

3. Use remaining water for transparency tube measurement if specified. If insufficient water is left, collect additional water until there is enough for replicate measurements.

Bottom Water

- From compositing jug - Rinse the bottle caps and bottles in composite water as for surface water.

- From VanDorn/Nisken - Carefully stand the Van Dorn or Nisken bottle on the side of the boat or on a seat, crack the top slightly to start the flow, rinse and dump 3 aliquots before filling the bottles to their necks. If there is not enough water in the Van Dorn to fill all the bottles, start over and either be more cautious with draining the sampler or use the compositing jug after rinsing as above. Two Van Dorn samples may be pooled. Cap loosely and agitate the jug before dispensing water into the plastic bottles for raw and filtered nutrients (probably the only analyses to be done for bottom water).

  Pay special attention to the appearance (visual color and turbidity) and smell (rotten egg gas, H_2S) of the water. If there is any evidence suggesting that bottom sediments were stirred up and captured by the sampler, re-do the collection taking care to vigorously clean the sampler and compositing carboy with surface water.

6.4.4 Sample Handling While in the Field

Store water samples in cooler with ice until return to home base for further processing.

In bad weather on lakes with a single sampling station or with a small boat it will be more convenient and safer to sample the bottom water first, collect the surface sample after the profiling is done, and then return to shore to pour the subsamples from a full compositing jug.

6.4.5 Quality Assurance of Field Duplicates

Collect a field duplicate every 10 samples. Label the replicate analysis bottles with the code appropriate for the replicate, and fabricate a date and time of sampling. Indicate on the data field form which site or lake is the replicate, the true sampling time and date, and the fabricated time and date. Treat the replicate as a regular sample for all phases of collection, processing, and analysis. The replicate should be a split sample, taken from the same composite jug. See section 6.6.3.2, below, for more details.

6.5 Departure from Monitoring Site

Before leaving the monitoring site, all field forms and sample labels must be reviewed for legibility, accuracy, and completeness. Any changes in procedure due to field condition must be explained in the comments section. Make sure the information is complete on all forms. Record the departure time on the field form. After reviewing each form, initial the upper right corner of each page of the form. Document any photos taken by including the photo number and roll number or digital camera photo number on the field form.

6.6 Quality Assurance/Quality Control (QA/QC)

QA/QC basically refers to all those things good investigators do to make sure their measurements are right-on (accurate; the absolute true value), reproducible (precise; consistent), and include good estimates of uncertainty. It specifically involves following established rules in the field and lab to assure everyone that the sample is representative of the site, free from outside contamination by the sample collector, and that it has been analyzed following standard QA/QC methods.

6.6.1 Calibration of Field Instrument Sensors

Calibration schedules overlap but differ from sampling schedules, so calibration methods are listed here as a separate procedural step. Instrument calibration is an essential part of quality assurance. Table 4 summarizes the ideal calibration frequency and minimum acceptance criteria for these sensor probes. The reality of logistical constraints at back country sites may preclude calibration and checks of calibration at the ideal frequency. This SOP provides only generic guidelines for equipment use and maintenance. A wide variety of field instruments is available; such instruments are continuously being updated or replaced using newer technology. Keep equipment manufacturers' maintenance and calibration instructions for all instruments for reference purposes. Field personnel must be familiar with the instructions provided by manufacturers. Contact manufacturers for answers to technical questions.

Table 4. Ideal calibration frequency and acceptance criteria.

Parameter	USEPA Method	Minimum Calibration Frequency and QC checks	Acceptance Criteria	Corrective Actions
Temperature thermometer:	170.1	Annually, 2-point check with NIST thermometer	±1.0 ºC	Re-test with a different thermometer; repeat measurement
Temperature thermistor:	170.1	Annually, 2-point check with NIST thermometer	±1.0 ºC	Re-test with a different thermometer; repeat measurement
Specific Conductance (SC25)	120.1	Daily, prior to field mobilization; calibration check prior to each round of sampling; 10% of the readings taken each day must be duplicated or a minimum of 1 reading if fewer than 10 samples are read.	±5% RPD 10%	Re-test; check low battery indicator; use a different meter; use different standards; repeat measurement
pH	150.1	Daily, prior to field mobilization (two buffers should be selected that bracket the anticipated pH of the water body to be sampled with an independent third buffer selected to check instrument performance in that range); Calibration check w/ third buffer prior to each round of sampling 10% of the readings taken each day must be duplicated or a minimum of 1 reading if fewer than 10 samples are read.	±0.05 pH unit ±0.1 pH unit RPD 10%	Re-test; check low battery indicator; use different standards; repeat measurement; don't move cords or cause friction/static
Dissolved Oxygen	360.1	Daily, prior to field mobilization; check at the field site if elevation or barometric pressure changed since calibration	0.2 mg/L concentration or ±10% saturation	Re-enter altitude; re-test; check low battery indicator; check membrane for wrinkles, tears or air bubbles; replace membrane; use a different meter; repeat measurement; allow more time for stabilization
Depth	--	Daily, prior to field mobilization, check at the field site. Check annually against commercially purchased brass sash chain labeled every 0.5 m to ensure that it reads zero at the surface and varies <0.3 m for depths <10 m and no more than 2% for greater depths.	±0.1 m	Retest, check low battery indicator; repeat measurement; use with accurately calibrated line
Transparency tube	--	Transparency tubes have a 100 or 120 cm scale; ensure tube is clean	±1.0 cm for transparency tube	
Marked lines (e.g., Secchi, Van Dorn)	--	Check markings annually against brass sash chain. If lines are heated (for decontamination) check prior to each round of sampling.	±1%, 0–10 m ±2%, >10 m	Re-mark line.

6.6.1.1 Instrument Calibration and Maintenance Logbooks

Calibration and maintenance logs for multi-parameter sondes and all back-up sensor probes will be maintained and will document the frequency of calibration, maintenance, and calibration checks. See the attachments for a blank calibration log form. Keep calibration logs with each instrument during the sampling season. Logs will later be archived at the Network office in Ashland, Wisconsin. A new log will be started for each field season. Each instrument will have a logbook for recording all maintenance and calibration information, including:

- serial number, date received, manufacturer's contact information, especially technical service representatives
- service records, dates of probe replacements
- maintenance records, for example, whenever the following general maintenance occurs: DO membrane replacement, pH reference probe junction and filling solution, probe cleanings, sonde (the sensor housing) replacement, impellor replacement or cleaning, etc.
- calibration dates and calibration data
- any problems with sensors
- pre-mobilization, post-calibration checks performed on individual sensor probes

6.6.1.2 Handling of Calibration Standard Solutions

Store all calibration standards in a temperature-controlled environment. Standards should be dated upon receipt and upon opening. Commercially-purchased calibration standards come with an expiration date that must be observed. Ensure that calibration standards are not used beyond expiration dates.

Properly dispose of all waste materials. Used calibration solutions, in general, may be rinsed down a sink with water after consideration of the wastewater treatment system available to that sink. Material safety data sheets (MSDS) that are sent with manufacturer purchased calibration solutions should be kept on file. These documents describe the flammability, toxicity, and other safety hazards of reagents. Some reagents may include constituents toxic to aquatic life. These should not be rinsed down a sink in any large quantities in primitive areas where the ultimate destination of wastewater is the aquatic environment. Instead, these reagents should be collected in a properly-marked leak-proof container for disposal in an adequate treatment system.

6.6.1.3 Temperature

Temperature is typically not adjustable on an electronic sensor but should be cross-compared to a National Institute of Standards and Technology (NIST) traceable thermometer at the beginning of each field season, as follows:

- Compare against a NIST-certified or NIST-traceable thermometer at a broad range of temperatures, for example 0 to 40 ^{o}C;
- The sensor should read within ± 1.0 ^{o}C of the NIST thermometer;
- Typically you cannot adjust the instrument to calibrate it but check the manual. It is a good idea to check the instrument at 0 ^{o}C in slurry of ice-water if a calibrated (NIST) thermometer is not available since electronic and non-electronic temperature sensors are typically linear over the likely range of field temperatures.

An armored glass thermometer that has been referenced to the NIST standard should be taken

into the field for air temperature and surface water temperature measurements and for checks of the electronic sensor.

6.6.1.4 Specific Conductivity

Specific conductivity (SC25) will be calibrated using a KCl solution as specified by the instrument manual. Stock calibration solutions can be purchased commercially, prepared by a water quality contract lab, or made in an academic or agency lab. If the KCl solution is prepared by an academic or agency lab, it should be cross checked by an external certified lab. Set the instrument to record temperature-compensated SC (SC25) rather than SC.

Because the typical modern SC25 sensor is linear to <3% over the range from approximately 20 to 10,000 μS/cm, a single point calibration is typically sufficient. A typical standard is 1000 or 1413 μS/cm. Pre-mobilization error checks of this sensor using 10, 100, 1413, and 10,000 uS/cm standards may be used to establish sensor error over the range of most interest in freshwater work.

6.6.1.5 pH

The pH is calibrated using the standard two buffer technique, using either pH 4 and pH 7, or pH 7 and pH 10, depending on the expected field values. Calibrate the probe according to the manufacturer's recommendations, usually starting with pH 7 buffer followed by the second buffer. If a water body is classified as low acid neutralizing capacity (ANC) acid-sensitive (i.e., ANC approximately 100 ueq/L or lower), it should also be checked against a low ionic strength buffer (LISB) with pH approximately 4, as per protocols from the National Acid Precipitation Assessment Program (NAPAP 1990). A low ionic strength pH combination electrode may be necessary to acquire this extra level of sensitivity if stabilized pH measurements are not achieved with standard pH sensors. Prior to each round of sampling, check the calibration with a third standard with a pH value between those used for calibration.

6.6.1.6 Dissolved Oxygen

Dissolved oxygen (DO) is typically air-calibrated, requiring current barometric station pressure. It assumes that the dry sensor will read 100% saturation in an enclosed airspace with enough water in the bottom of the container to saturate the air with water vapor. Temperature also affects the saturation as does the air pressure, which varies with elevation and ambient weather. Typically, one can assume the barometric pressure to vary with elevation, but some additional accuracy may be gained by either using a calibrated barometer, or consulting the local weather bureau or airport. The instrument should be re-calibrated at each site if the elevation has changed more than 50 feet. Some multiparameter sondes have the capability to measure barometric pressure.

6.6.1.7 Depth

The length measurement of brass Secchi chains, transparency tubes, and depth sounders usually require little calibration after purchase and an initial check for accuracy. Compare all depth cables to each other and ensure they are synchronized. A brass Secchi chain can be used to calibrate other cables and lines. The use of a brass chain is particularly important because this single tool is likely to provide consistent long-term data. Nylon and certain braided weave ropes and cords can stretch as much as 20% and may vary depending upon wetness, load, and age.

Lines may also shrink, as when they are soaked in hot water to avoid spread of exotic species.

Electronic depth sensors, or pressure transducers, are based on pressure differences and need to be set to zero at the water surface initially. Perform this zero check at every station; however, verify the depth measurement with labels on the actual instrument cable.

A useful and widely-used labeling system for coding depths is:

1. 5 m increments: Wrap vinyl tape of a specified color at 5 m increments and add an extra wrap every 5 m. Therefore, there is a single wrap at 5 m: two wraps at 10 m separated by ~ 0.5 cm with 10 m lying exactly between the wraps; three wraps at 15 m with the 15 m depth located at the middle of the second wrap, and so on. A permanent marking pen should be used to write the actual depth on the tape.
2. 0-10 m depth: Use a second color to make wraps at 1 m intervals to best define shallow water columns.
3. 10-20 m depth: Use the second color, or new third color, to wrap at 2m intervals.
4. >20 m: Mark the line at 2.5 m intervals or continue with 2 m intervals.

6.6.1.8 Post-Field Calibration Checks

Post-field calibration checks must be performed after each use of the instrument and before any instrument maintenance. The sooner this procedure is performed, the more representative the results will be for assessing performance during the preceding field measurements. Calibration and post-calibration should be no more than 24 hours apart. When sampling daily, the second day's calibration can serve as the first day's post-field calibration check. Take the same care used in performing the initial calibration by rinsing the sensors and waiting for sensors to stabilize. After making measurements at the last station, fill the sampling cup with ambient water (not deionized or tap water). Repeat the initial calibration procedures performed before the sampling trip. Record post-field calibration values in the calibration logbook (generally on the same page with the initial calibration for that sampling trip). Deviation beyond the manufacturer's specifications is cause for concern and should be addressed before the next sampling date.

Do not adjust the instrument (using calibration controls) during the post-calibration check.

The purpose of the post-calibration is to determine if the instrument has held calibration during the day of sampling. Compare the post-calibration values to the expected values for the standards. This will ensure that the field measurements for the day can be reported with confidence. The difference between the post-calibration value and expected standard value can be used to indicate both calibration precision and instrument performance.

If post-calibration values (Table 5) fall outside the error limits for DO, pH, and specific conductance, data collected do not meet quality assurance (QA) standards and should be flagged appropriately (see SOP #12 for more details on QA/QC). Measurements may be repeated with a different or back-up instrument. If post-calibration measurements do not consistently fall within the error limits after in-house trouble shooting, the instrument should be returned to the manufacturer for maintenance.

Table 5. Post-calibration check error limits.

Parameter	Value
Temperature	± 1 °C, annual calibration check
Specific Conductance	± 5%
pH	± 0.1 standard units
Dissolved Oxygen	± 0.2 mg/L, ± 10% saturation

6.6.1.9 Sensor Maintenance and Storage

Most multiparameter sondes should be stored with a small amount of water in the storage cup. Refer to the manufacturer's manual for tips on cleaning the probes and housing, routine maintenance procedures, and proper storage procedures.

6.6.2 Calculation of Field Instrument Performance Criteria

Performance of field instruments must be checked in several ways, as detailed in the QA/QC procedures of SOP #12. Formulae for calculating instrument sensitivity, instrument precision, instrument bias, and cumulative bias are found in SOP #12.
Documentation of these performance criteria include estimation of the limits of detection of the multiprobe, the relative percent difference of duplicates, measurement of reference solutions, and estimates of change due to change in methods or instrumentation.

6.6.3 Quality Assurance/Quality Control Samples

Quality control samples are commonly used in documenting quality control associated with the collection of samples in the field. Field blanks and duplicates are routinely incorporated into a monitoring program without a good understanding of their function. The purpose of these samples is to validate the precision and accuracy of laboratory data, and to determine the adequacy of preservation techniques, equipment cleaning and preparation, and sampling procedures. Field blanks are used to measure and quantify the amount of contamination from extraneous sources (preservatives, sample bottles, sample handling, automatic samplers, etc.) that might compromise the integrity of a sample (alter its true value or concentration).

6.6.3.1 Equipment Blanks

Blanks are an integral part of quality control (QC) and are required for all sampling activities. Their creation should be noted in the field log book. Blanks establish that there is no sample contamination from the containers during custody, transportation, and or pre-analysis preparation either in the field or in the laboratory. Blanks establish the level of constituents introduced into a sample by the equipment used for sampling, preservatives, and/or containers. We will conduct equipment blanks prior to each field season and occasionally during the field season between field sites to ensure field rinsing is adequate.

Collect an equipment blank prior to the field season as follows:

1. Clean all equipment used to collect, store, and process water samples (e.g., integrating

sampler, compositing jug, filtering apparatus) according to SOP #7.
2. Rinse the equipment used to collect and store water samples (integrating sampler and compositing jug) with laboratory reagent grade water three times and discard.
3. Fill the integrating sampler with a fourth aliquot of laboratory reagent grade water and handle and process this aliquot as if it were a lake sample to be analyzed.

Another source of systematic error is sample cross contamination from field sampling equipment used to handle a multiple number of samples. The integrated sampler and compositing jugs are to be rinsed in the field three times at each site prior to taking a sample. Either piece of equipment may be a source of cross contamination. Collect periodic equipment blanks as follows:

1. In between sample sites, rinse the equipment used to transfer water samples (integrating sampler and compositing jug) with laboratory reagent grade water three times and discard.
2. Fill the integrating sampler with a fourth aliquot of laboratory reagent grade water and handle and process this aliquot as if it were a lake sample to be analyzed.

This sample is labeled as an equipment blank and information kept on a datasheet describing the source of the blank. Results for all parameters should be non-detect. This type of blank is a check for cross contamination between sampling sites and control for bias introduced by cross contamination.

Other types of blanks will be used as needed: field sampling conditions or ambient blanks, if there is any reason to suspect that ambient air pollution has the potential to contaminate water quality samples; preservative blanks, if there is any reason to suspect that a preservative may be contaminated; or bottle blanks, any time sample collection bottles are of uncertain quality or cleanliness or from a source not previously used.

6.6.3.2 Sampling Duplicates

The purpose of a duplicate sample is to estimate the inherent variability of a procedure, technique, characteristic or contaminant. Duplicate samples are collected and duplicate analyses may be made in the field: 1) as a form of field quality control; 2) to measure or quantify the homogeneity of the sample, the stability and representativeness of a sample site, the sample collection method(s) and/or the technician's technique.

Duplicates are analyzed in the laboratory for the same parameters as the monitoring sample to which they apply. Laboratory duplicates which exceed QA/QC standards for the parameter are retested. Analytical results of duplicate samples will, theoretically, be the same. Realistically, results may differ due to the non-homogeneity of the sample source, and sampling and analytical errors. Duplicate samples also document the technique and ability of the technician and analyst to produce representative water quality data.

The laboratory analytical report must show test results for the duplicates, blanks and spikes, the method and the results for summary quality control statistics calculations. Copies of these reports are a permanent part of the site file.

Duplicates will ideally be splits of homogeneous samples to estimate measurement precision in the context of repeatability unless otherwise documented and justified. If enough sample water cannot be collected in the compositing container to facilitate a split sample, then duplicate samples will be co-located.

Duplicate field samples must be collected every sampling trip for each type of sample collected and the results must have a Relative Percent Difference (RPD) less than or equal to the guidelines in Table 6. Required field parameter measurements can be duplicated to estimate the precision of the equipment. Every tenth measurement may be duplicated, and the results of both measurements recorded and evaluated as RPD. The result can be compared with the stated precision of the instrument.

Table 6. Frequency, acceptable range, and corrective actions for duplicate samples.

Type of Duplicate	Frequency	Acceptable Range for Precision	Corrective Action
Field duplicates (samples)	Minimum of 1 per trip per parameter or 10% of all samples per parameter per day	Chlorophyll-a, TSS and nutrients ± 30% RPD; all other parameters ±15% RPD	Audit field personnel and verify sample collection procedure; resample; reanalyze; revise SOP; audit and train field personnel; project manager determines whether associated data is usable
Field duplicates (multi-probes)	Minimum of 1 per trip per parameter or 10% of all samples per parameter per day	All parameters ±10% RPD	Re-calibrate instrument; replace batteries; perform instrument field check with different standards; repair or replace instrument; notify management; audit and train field personnel; project manager determines whether

6.6.4 Summary of Quality Assurance/Quality Control Field Procedures

Quality assurance protocols are means to ensure data collected are as representative of the natural environment as possible. Quality assurance procedures are required in all data collection efforts as part of this monitoring protocol. Many of the key elements of quality assurance have been included in the SOPs where appropriate, as well as detailed in SOP #12. A summary of important QA/QC procedures follows. Table 7 lists additional requirements for QA/QC methods and documentation.

Table7. Summary of QA/QC documentation and sampling methods.

Procedure	Description/reason
Instrument calibration logs	Each instrument must have a log in the form of a permanently bound logbook. Calibration schedule must be observed, using fresh calibration standards.
Project binder	Containing: checklist of QA/QC reminders, copies of decontamination, sample collection and processing SOPs, copies of equipment calibration and troubleshooting instructions, ASR and COC forms, blank field forms.
Site binders	Containing: GPS coordinates for verification of correct sampling location, table of previous field measurements to compare with new measurements
Field forms	Field forms are the only written record of field measurements, so copies are placed in site binders and originals must be kept on file indefinitely.
Field instrument methods	Require consistent measurement methods and detection limits
Sample preservation and minimum holding time	Water quality variable concentrations are maintained as close to sampling conditions as possible.
Chain-of-custody	A chain-of-custody includes not only the form, but all references to the sample in any form, document or log book which allow tracing the sample back to its collection, and documents the possession of the samples from the time they were collected until the sample analytical results are received.
Laboratory methods	Require consistent analytical methods and detection limits

- Field staff must be trained by an expert hydrologist(s). Training will include classroom time as well as field and lab components. Details of the training are given in the Standard Operating Procedure #2: Training and Safety.

- Use calibrated instruments for all field measurements. Test and/or calibrate the instruments before leaving for the field. Each field instrument must have a permanent log book for recording calibrations and repairs. Review the log book before leaving for the field.

- All manually recorded field measurement data will be collected on field forms; data that are automatically recorded will be captured electronically and the equipment used will be documented on field forms. Hard and electronic copies will be made as soon as possible after surveys and kept at a separate location as backup.

- Complete records will be maintained for each sampling station and all supporting metadata

will be recorded appropriately (field forms or electronically).

- Make field measurements in a manner that minimizes bias of results.
- Check field-measurement precision and accuracy. Follow the procedures in SOP #12.
- Collect 10% duplicate water samples; conduct duplicate measurements of field parameters at approximately 10%.
- Create field blanks prior to the beginning of each field season and periodically throughout the season.

6.6.5 Corrective Responsive Action

The project manager, in consultation with experienced professionals, will be responsible for taking corrective responsive action in the case in which QA/QC is not followed or in the case of an unexpected event. Responsive action is often needed in the event of broken sample bottles, missing data, errors on field sheets, changes due to field conditions, problematic analyses and other events that do not fall within the standard operating procedures. A "Memo-to-file" will be used to document any decisions or corrections that are made. This memo will include the date, name of author, site or sample referred to, a description of the problem or error and a statement describing the decision made or action taken. The memo will be archived with the appropriate site data and files.

6.7 Data and Records Management

- Hand-written field sheets with core suite profiles should be reviewed for completeness immediately upon returning to the shore. Make photocopies as soon possible and file them appropriately. Download and back up data from the multisensor datalogger as soon as possible.
- Ensure that field forms, field notebooks, and other hardcopy records are secure, organized, and available for viewing, reproduction, or transfer upon request and/or at the end of each field season.
- Schedule and perform regular data transfer and backup. Data will be protected from loss or damage by daily backup, when possible, or on a feasible schedule approved by the project leader and the data manager. Ideally, raw data are backed up off-site as soon as a sampling trip is completed.
- Record and verify observed or measured data values. Complete paper forms and enter data into NPSTORET and/or other electronic databases.
- A 'Memo-to-file' will be used to document any decisions or corrections that are made. This memo will include the date, name of author, site or sample referred to, a description of the problem or error, and a statement describing the decision made or action taken. The memo

will be archived with the appropriate site data and files.

- Data validation, the process by which data are proven or disproved to be accurate, involves the review of the results of all measurements, samples, and QC samples. Sample data should be flagged if the analyte was detected in a blank at a concentration similar to that in the sample; flagged data contain much more uncertainty than unflagged data. Some investigation into the sampling method may be needed if flagged data are a continual occurrence.

- Refer to SOP #8 for more details regarding data entry and management.

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Attachments

- Field Data Sheet
- Multiprobe Calibration Log
- Eureka Manta Maintenance Log
- Multiprobe Calibration/Maintenance Log

Eureka Manta Multiprobe Calibration

Personnel _____ **Date** _____

Eureka Manta Multiprobe #309050132

DO Membrane Changed _____ **Date** _____

pH Reference Electrolyte Changed

Time _____ **Date** _____

	Calibration Standard (True Value)	Pre Calibration Reading	Calibration Reading	Calibration Check	Pre- or Post-Field?
Battery Voltage					
Depth	**0**				
SpCond (µS/cm) Air	**(0)**				
SpCond (µS/cm)	**value Lot#**				
SpCond (µS/cm)	**value Lot#**				
SpCond (µS/cm)	**value Lot#**				
Temperature					
pH	**7 Lot#**				
pH	**10 Lot#**				
pH	**4 Lot#**				
pH	**Lot#**				
Baro Press.					
DO% Saturation					
DO (mg/L)					

Eureka Manta Maintenance log					
Record maintenance performed, date, and person conducting maintenance					
Date & Personnel	**DO Probe**	**pH probe**	**EC25 probe**	**Temperature**	**Depth Sensor**

MULTIPROBE CALIBRATION/MAINTENANCE LOG

PRE FIELD CALIBRATION
Calibration _____ Initials:_____ Sonde ID:_____ Date:_____ Time: _____Instrument:_____ Battery Voltage:_____

Function	Temp. of Standard	Value of Standard	Initial Reading	Calibrated to	Comments
Specific conductance					
pH calibrated (~7)					
pH secondary standard (4 or 10)					
Dissolved oxygen					

DATA NEEDED FOR DISSOLVED OXYGEN CALIBRATION

Altitude (A)=_____feet above msl	Barometric pressure _____ inches
Barometric Pressure (BP) Options	**Barometric Pressure Formulas**
Barometer	Barometric pressure (inches) _____ x 25.4 = BP _____mm
From local source after correction (CBP)	BP _____ mm = CBP _____mm - 2.5 (altitude ____/100)
Estimated from altitude only	BP _____ mm= 760 mm - 2.5 (altitude _____/100)

For older Hydrolabs: Table DO value_____ x ALTCORR_____ x BAROCORR _____= DO standard _____

POST FIELD CALIBRATION CHECK Post Calibration Initials: Date: Time: Instrument: Battery Voltage: date of original calibration _____

Function	Temp. of Standard	Value of Standard	Initial Reading	Calibrated to	Comments
Specific conductance					
pH 7					
pH secondary standard (4 or 10)					
Dissolved oxygen					

Check previous maintenance and use; do the following before calibration:

Polish conductivity electrodes. Must be polished within the last two months or once every 15 field trips	Date:	Name/comments:
Change pH reference probe solution. Must be renewed within last two months or once every 15 field trips.	Date:	Name/comments:
Inspect DO membrane for nicks or bubbles. Must be changed within last six months or once every 15 field trips.	Date:	Name/comments:
Change battery. Change once a year. Change internal batteries for newer generation products according to guidelines in product manual.	Date:	Name/comments:

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Standard Operating Procedure #7: Processing Water Samples and Analytical Laboratory Requirements

Version 1.0

In **Water Quality Monitoring Protocol for Inland Lakes**

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Revision History Log

The following table lists all edits and amendments to this document since the original publication date. Information entered in the log must be complete and concise. Users of this standard operating procedure will promptly notify the project manager and/or the Great Lakes Network (GLKN) data manager about recommended and required changes. The project manager must review and incorporate all changes, complete the revision history log, and change the date and version number on the title page and in the header of the document file. For complete instructions, please refer to Revising the Protocol, SOP #13.

Revision History Log:

Previous Version #	Revision Date	Author (with title and affiliation)	Location in Document and Concise Description of Revision	Reason for Change	New Version #
Add rows as needed for each change or set of changes tied to an updated version number					

Acknowledgements

Combinations of existing protocols were used to develop this standard operating procedure for handling and processing water samples prior to sending them to an analytical laboratory. The authors wish to acknowledge these sources (Hoffman et al. 2005, O'Ney 2005, USGS 2005, WOW 2004, Penoyer 2003, EPA 2001, and Baker et al. 1997) for the guidance they provided. Thanks also go to White Water Associates for providing examples of forms for analytical requests and chain of custody.

7.0 Introduction

As part of our water quality monitoring program, we will collect water samples for analysis of basic limnological parameters that may respond to stressors such as atmospheric deposition, land use change, and recreational pressures. Because neither the GLKN nor the individual park units currently have certified laboratories and instrumentation for performing these analyses, water samples will need to be processed soon after collection for transport to a suitable laboratory. This will require filtering and preserving subsamples of water and filters according to methods specific to the analyte. This standard operating procedure (SOP) is designed to provide detailed instructions on the handling and processing of water samples prior to analysis by an analytical laboratory.

We will collect water in the field (SOP #6) for the analysis of the following parameters:

- Nutrients: total phosphorus (TP), total nitrogen (TN), nitrate+nitrite-N (NO_3+NO_2-N), and ammonium-N (NH_4-N)
- Chlorophyll-*a*
- Major anions ($SO4^{-2}$ and Cl^-);
- Alkalinity
- Major cations (Mg^{+2}, Ca^{+2}, Na^+, K^+)
- dissolved Silica (SiO_2)
- dissolved organic carbon (DOC)

Water chemistry will be performed by one or more analytical laboratories that have demonstrated the ability to measure analytes at detection levels adequate to meet our needs. Preferably, the laboratories will be state- or federally-certified for performing the above water chemistry analyses in natural waters, or an academic research laboratory that can demonstrate quality assurance and quality control (QA/QC) procedures consistent with SOP #12 and current EPA procedures used as the basis for state certification of commercial environmental laboratories. The GLKN's preference is for laboratories to provide clean sample bottles and preservatives, where appropriate, as well as chain of custody documentation and sample logging.

7.1 Summary of Analytical Methods

Analytical methods, method detection limits, and procedures related to handling samples change over time as the science progresses. Table 1 summarizes examples of the variety of methods, detection limits, preservation techniques, and holding times for water samples addressed in this protocol. Table 2 summarizes the frequency at which water samples will be collected for analysis.

Table 1. Examples of analytical methods, method detection limits (MDLs), containers, and holding times.

Analyte	Analytical *Note 1*	Method #	Det. Limit	Vol. (ml)	Filter	Preservation	Sample Bottle *Note 2*	Hold Time
Alkalinity	Titrimetry	310.1 EPA-NERL	10 mg/L			4°C		14 days
	Spec. auto.	310.2 EPA-NERL	10 mg/L			4°C		14 days
	Titrimetry	NFM USGS-OWQ	0.01 meg/L		*Note 4*	None		none
	ICP	3120B APHA	10 ug/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
Calcium	Titrimetry	215.2 EPA-NERL	0.5 mg/L		*Note 3*	4°C		6 mos
	FAA	I-3152 USGS-NWQL	0.1 mg/L	250 mL	*Note 3*	pH<2 HNO_3	P	180 day
Chloride	IC	300.0 EPA-NERL	0.02 mg/L			4°C	P or G	28 day
	Colorimetry	325.2 EPA-NERL	1 mg/L			4°C		28 day
	Titrimetry	4500-Cl APHA	0.15 mg/L	100 mL		4°C	P or G	28 day
Chlorophyll-a	Spect.	10200 APHA	2 ug/L	≤ 1 L	*Note 4*	Freeze filter	P	30day
Color	Spect.	110.2 EPA-NERL	5 Pt units		*Note 5*	4°C	G	48 hours
	Vis. Comp.	I-1250 USGS-NWQL	1 Pt-co	250 mL	*Note 5*	4°C	P	30 days
DOC	Spect.	415.3 EPA	0.018 mg/L	125	*Note 3*	pH<4 H_2SO_4	G	28 days
	Spect.	0-1122-92 USGS	0.1 mg/L			4°C	AG	
K	ICP	3120B APHA	0.3 mg/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
	FAA	3111B APHA	5 ug/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
Mg	ICP	3120B APHA	20 ug/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
	FAA	3111B APHA	0.5 ug/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
Na	ICP	3120B APHA	30 ug/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
	FAA	3111B APHA	2 ug/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
NH_4-N	Selective elec.	4500-NH_3E	0.08 mg/L			4°C/pH2,0°C		24h/28d
	Colorimetry	350.2 EPA-NERL	0.08 mg/L			pH<4 H_2SO_4		28 day
	Titrimetry	4500-NH_3 APHA	5 mg/L			4°C/pH2,0°C		24h/28d
SiO_2	ICP	3120B APHA	20 ug/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
	Spect.	4500- SiO_2 D APHA	0.04 mg/L		*Note 3*	No, 4°C	P	28 days
	FIA-Spect.	4500- SiO_2 F APHA	0.78 ug/L		*Note 3*	No, 4°C	P	28 days
TSS	Gravimetric	I-3765 USGS-NWQL	1 mg/L	250-500	*Note 4*	4°C filter	P	NA
SO_4	IC	4110C APHA	75 ug/L		*Note 3*	pH<4 H_2SO_4	P or G	
	CIE-UV	D6508 ASTM	0.1 mg/L		*Note 3*	pH<4 H_2SO_4		ASAP
	Spect.	37512 EPA-NERL	0.5 mg/L		*Note 3*	pH<4 H_2SO_4	P or G	28 days
TP	Spect.	I-2606 USGS-NWQL	0.001 mg/L	125 mL		MgCl 4°C	BrownP	30 days
	Alkaline P	USGS 2003	0.01 mg/L	120 ml	*Note 6*	4°C /H_2SO_4		48 h/30d
	ICP	200.7 EPA-NERL	60 ug/L			pH<2 HNO_3	P	6 mos
	Alkaline P	USGS 2003	0.03 mg/L	120 ml	*Note 6*	4°C /H_2SO_4		48 h/30d
TN	Titrimetry	4500-N	0-100 mg/L			4°C	AG	7 days
	Combustion	440.0 EPA-NERL	0.1 mg/L			Filter		100 day

Source: National Environmental Methods Inventory website (NEMI 2006)

This list is not an endorsement of any particular method or laboratory for any particular analyte. Rather it is to be used as a reference for the range of analytical methods available for each analyte. There are surface water conditions (pH, turbidity, other elements) that make a particular method unsuitable for a particular situation. As GLKN is monitoring surface water, the methods listed were chosen as representative of the lower range of detection limits.

Note 1. CIE-UV= capillary ion electrophoresis with UV detection, FAA = flame atomic absorption, FIA = flow injection analysis, IC= ion chromatography, ICP = inductively coupled plasma, Spec. auto = spectroscopy with autoanalyzer

Note 2. P = plastic (polypropylene), G=glass, AG=amber glass

Note 3. 0.45µm membrane filter. Pre-filter for dissolved portion analysis.

Note 4. 0.45µm glass fiber filter.

Note 5. 0.45µm membrane filter or centrifuge is recommended to remove suspended solids that affect color, however some color will also be removed.

Note 6. USGS 2003. Evaluation of Alkaline Persulfate Digestion as an Alternative to Kjeldahl Digestion for Determination of Total and Dissolved Nitrogen and Phosphorus in Water By Charles J. Patton and Jennifer R. Kryskalla. U.S. Geological Survey Water-Resources Investigations Report 03-4174.

Table 2. Frequency of analyses of water samples and depths at which samples will be collected. Surface samples will be a 0 - 2 m integrated sample. Bottom samples will be collected during mid-summer, if a lake is stratified.

Water Quality Variables	Monitoring Frequency
Total phosphorus (TP)	3x/yr, surface 1x/yr, bottom
Total Nitrogen (TN)	3x/yr, surface
Nitrate + Nitrite-Nitrogen (NO_3+NO_2-N)	3x/yr, surface
Ammonium-Nitrogen (NH_4-N)	3x/yr, surface
Major Anions ($SO4^{-2}$, Cl^-)	1x/yr; surface
Alkalinity	1x/yr; surface
Major Cations (Mg^{+2}, Ca^{+2}, Na^+, K^+)	1x/yr; surface
Dissolved silica (SiO_2)	1-2x/yr; surface
Dissolved organic carbon (DOC)	1x/yr; surface
Total chlorophyll-*a*	3x/yr; surface

7.2 Sample Handling and Processing Procedures

The following general techniques will be observed throughout the procedures detailed in 7.2.1 through 7.2.4.

1. Keep all water samples cool and dark until processing is complete and samples are shipped to the analytical laboratory.

2. Use only new, clean sample bottles supplied by the analytical laboratory or purchased pre-cleaned from a supplier.

3. Rinse filtration equipment with deionized water (DIW) three times between samples.

4. Avoid touching the inside of sample bottles and filtering apparatus, tips of forceps, and filters to prevent contamination of the samples.

5. When filtering samples in the field, use an enclosed filtering apparatus to minimize contamination from airborne sources.

6. Wear disposable, powderless gloves when working with acids and other preservatives.

7. Filter samples in the order of anticipated phosphorus concentrations, from low to high.

After filtering a water sample that is expected to contain high nutrient concentrations, rinse the apparatus three times with 0.1N HCl followed by three times with DIW water before processing the next sample.

8. Prepare QA/QC samples in the same manner as regular samples, using water from the same sample collection container.

9. Rinse all reusable equipment with DIW immediately, before equipment dries.

10. Ensure all sample bottles are labeled correctly, completely, and legibly.

11. Check laboratory equipment and supplies list (Table 3) and ensure equipment is clean and ready for use and supplies are adequate.

12. Prepare a temperature check bottle for each anticipated cooler, if recommended by the contract analytical laboratory. Use tap water to fill an extra bottle of the same size used for one of the analytes and label as "Temperature Check". Store this check bottle in refrigerator with other samples; package and send to the analytical laboratory with the other samples.

Table 3. Laboratory equipment and supplies list.

- Filtration towers and manifold (4.7 mm) plastic
- Vacuum pump with pressure gauge and extra filtering flask as a water trap to protect the pump in case of overflow
- Graduated cylinders, plastic 250, 500 and 1000 mL
- Whatman GF/C filters (4.7 cm diameter)
- 0.45 μm Millipore membrane filters (4.7 cm diameter)
- Filter forceps with broad tips
- Aluminum foil
- Labeling tape, permanent markers
- Deionized water (ASTM grade 1 or 2; 1-10 megohm)
- Acid for preservation (according to contract laboratory specifications)
- Freezer
- Plastic storage bags
- Sample bottles (provided by analytical laboratory)
- Insulated ice chest, ice, and ice packs
- Saturated MgCO3 solution (for chlorophyll *a*), depending on laboratory method
- Adjustable automatic pipettes: 1-5 mL ; 0.2-1 mL; 0.02 -0.1 mL
- Parafin paper roll
- Wash (squirt) bottles – 500 mL
- Kim wipes

The following sections detail the procedures to be followed when processing water samples for particular analysis.

7.2.1 Total Chlorophyll-*a*

1. Fit rinsed filtering device with a Whatman GF/C glass fiber filter using forceps, smooth side down (curl is up).

2. Agitate water sample (always shake well to minimize subsampling error for solids).

3. Set pump vacuum to $\leq$ 0.5 atmospheres (7.5 PSI or 380 mm Hg). If using a hand pump, maintain pressure at or below 10 PSI.

4. Use a glass or plastic graduated cylinder to measure 100 - 1000 mLs of water sample. Filter sample. If water is very turbid, filter small aliquots (100 mLs) to avoid clogging the filter. Sufficient volume has been filtered when a green, brown, or tan color is clearly visible on the filter and the flow decreases to a few drops/second.

5. Add 0.15mls (~3 drops) of saturated $MgCO_3$ during the last 30 mLs of filtering to buffer the filter, if required by the method used by the contract analytical laboratory.

6. Rinse graduated cylinder and filtering apparatus with DIW and pass through filter to include any algae that may have adhered to the sides of the cylinder.

7. Record volume filtered on data sheet (excluding DIW rinse).

8. Use forceps to fold filter into quarters with sample on the inside; do not touch filter with fingers.

9. Wrap filter in foil; label foil with sample location, date and time sample was collected, and volume filtered. Place foil in small, sealable baggie with standard laboratory label.

10. Refrigerate immediately and freeze as soon as possible. Place small baggies with foils together in a large, sealable freezer bag. A third watertight container may be used for shipping to ensure that melt water in transport will not corrupt the samples.

7.2.2 Unfiltered (Raw) Samples

a. TN and TP
- Rinse sample bottle provided by contract analytical laboratory 1x with sample water
- Fill sample bottle with sample water (fill to neck if sample will be frozen)
- Refrigerate or freeze, as per laboratory instructions, until packaging for transport to analytical laboratory

b. Alkalinity and anions
- Rinse sample bottle provided by the analytical laboratory 1x with sample water
- Fill sample bottle with sample water
- Refrigerate until packaging for transport to analytical laboratory

7.2.3 Filtered Samples: (NO_3+NO_2-N, NH_4-N, Cations, DOC, and SiO_2)

1. Using clean forceps, place a 0.45µm Millipore cellulose membrane filter in the filtration apparatus. Rinse with 100 mL DIW into a cleaned (0.1N HCl and DIW rinsed as per sample bottle cleaning) filtering flask (glass or plastic). Rinse flask with filtrate and discard filtrate.

2. Filter a small amount (~50 ml) of sample water; rinse filtering flask with filtrate and discard filtrate.

3. Filter enough of the sample to produce the required amount of filtrate to be tested.

4. Dispense the filtrate into separate bottles provided by the analytical laboratory as follows:
   - dissolved nutrients – rinse bottle with small amount of filtrate (~10 ml) and discard; fill bottle to neck, refrigerate or freeze as per laboratory instructions.

   - major cations - if pre-loaded with HNO_3 preservative by the analytical laboratory, fill bottle and store at room temperature or refrigerate. If bottle does not come pre-loaded with preservative, rinse bottle with small of amount of filtrate (~10 ml) and discard, fill bottle approximately ¾ full, add the HNO_3 preservative (ampule provided by laboratory) and continue to fill bottle until full. Gently roll bottle to mix. Store at room temperature or refrigerate.

   - DOC - if pre-loaded with H_2SO_4 preservative, fill bottle. If bottle does not come pre-loaded with preservative, rinse bottle with small of amount of filtrate (~10 ml) and discard, fill bottle approximately ¾ full, add the H_2SO_4 preservative (ampule provided by laboratory) and continue to fill bottle until full. Gently roll bottle to mix. Store at room temperature or refrigerate.

   - Silica – rinse bottle with small of amount of filtrate (~10 ml) and discard, fill bottle and refrigerate.

7.3 Shipping Procedures

1. Call FedEx or other courier service ahead of time to arrange pick-up.

2. Make large quantities of ice cubes and ice blocks (or buy ice) ahead of time.

3. Line cooler with large plastic garbage bag.

4. Place all total chlorophyll-*a* baggies containing aluminum foil wrappers in one large sealable plastic bag. Place this baggie between 2 ice packs or bags of ice. It is critical that melt water does not soak the filters, so you may want to place large sealed bag of foil wrappers in a sealed plastic jar before surrounding with ice.

5. Use ice cubes, doubly bagged in plastic bags, to pack around samples; use other ice blocks (water bottles, soda bottles, etc.) as they will fit.

6. Include a temperature check bottle with the sample bottles in each cooler, if used by the contract analytical laboratory.

7. Complete the chain of custody (COC) form, keeping the 'client copy' for the project files. Seal the laboratory's copies in a one-gallon plastic sealable bag and tape to the inside cover of the cooler. Prepare separate COC forms for each cooler. An example COC form is provided in Attachment B.

8. If the refrigerated samples are sent in the same insulated cooler with the frozen samples, protect them from freezing by wrapping them in newspaper, bubble wrap, etc.

9. Ship samples overnight so they are received the following day during a work-week, whenever possible. Contact the laboratory about Saturday shipment receipt availability before shipping samples on a Friday. Many laboratories do not have sample receipt staff on Saturday or charge extra for staff time.

10. Alert the contract laboratory when samples have been shipped and provide them with the tracking number.

7.4 Quality Assurance/Quality Control

Quality assurance/quality control refers to all those things good investigators do to ensure their measurements are accurate (the absolute true value) and precise (reproducible, consistent), and that they include a good estimate of their uncertainty. It specifically involves following established rules in the field and laboratory to assure everyone that the sample is representative of the site, free from outside contamination, and that it has been analyzed following standard QA/QC methods. These methods typically involve comparing the sample to a set of known samples for estimating accuracy and replicating the measurement to estimate its precision.

In the context of field sampling and processing, quality assurance protocols are meant to ensure that data collected are as representative of the lake or stream site as possible. Such procedures include implementing good field procedures and quality-control checks, careful post-collection processing of water samples to minimize artifacts due to contamination or mis-labeling, proper storage and preservation techniques while in transit to a laboratory, and proper QA/QC by the laboratory itself. See SOP #12, Quality Assurance/Quality Control, for more details.

Quality assurance at the batch level (within the laboratory) is accomplished by using proper techniques and replicating 10% of the field samples.

The most important aspects of quality control in the collection of water quality samples are: 1) Samples collected should represent the lake site at the time the samples are collected, such that the samples produce the quality of information necessary to meet the objectives of the survey;

and 2) the integrity of the samples collected is not compromised by contamination, misidentification, or improper sample handling or preservation.

To help meet these quality control aspects, the transport and tracking of the samples from the field to the analytical laboratory that performs the chemistry analyses is critical. Each set of samples should include an Analytical Services Request (ASR) form supplied by the laboratory (see Appendix B for an example), which accompanies a Chain of Custody Form. To ensure correct processing of samples, the information recorded on the ASR form must correspond to each sample in the shipment. Check with individual analytical laboratory requirements for correct labeling codes and procedures. To prevent water damage to paperwork accompanying samples to the laboratory (such as the ASR form and the Chain of Custody form), place all paperwork inside two sealable plastic bags and tape the bags to the underside of the cooler lid. Keep a copy of the completed ASR and COC forms in the office binder.

7.5 Data and Records Management

Complete and accurate record keeping of field-derived data is an essential component of monitoring water quality. Field technicians, crew leaders, and project leaders share responsibility for collecting, verifying, and documenting data according to the guidelines in this monitoring protocol and all applicable standard operating procedures. Data and records management include the following responsibilities:

1. Refer to the GLKN Data Management Plan (Hart and Gafvert 2006) for overall guidance.

2. Follow the QA/QC procedures in SOP #8 for specific instructions on data entry, management, verification, and validation.

3. Record and verify observed or measured data values, including completing paper forms and entering data into NPSTORET and/or other electronic databases. NPSTORET maintains the necessary relationships between data values, equipment configuration and calibration, procedures, methods, and metadata.

4. Schedule and perform regular data transfer and backup. Data will be protected from loss or damage by daily backup when possible, or on a feasible schedule approved by the project leader and the data manager.

5. Review, verify, and correct field data and sample processing information as soon as possible after the actual survey (see SOP #8 for more details).

6. Prepare data and procedural documentation, especially deviations from the protocol or study plan, including metadata forms in NPSTORET and additional documentation requested by the project manager or data manager.

7. Ensure that field forms, field notebooks, and other hardcopy records are secure, organized, and available for viewing, reproduction, or transfer upon request.

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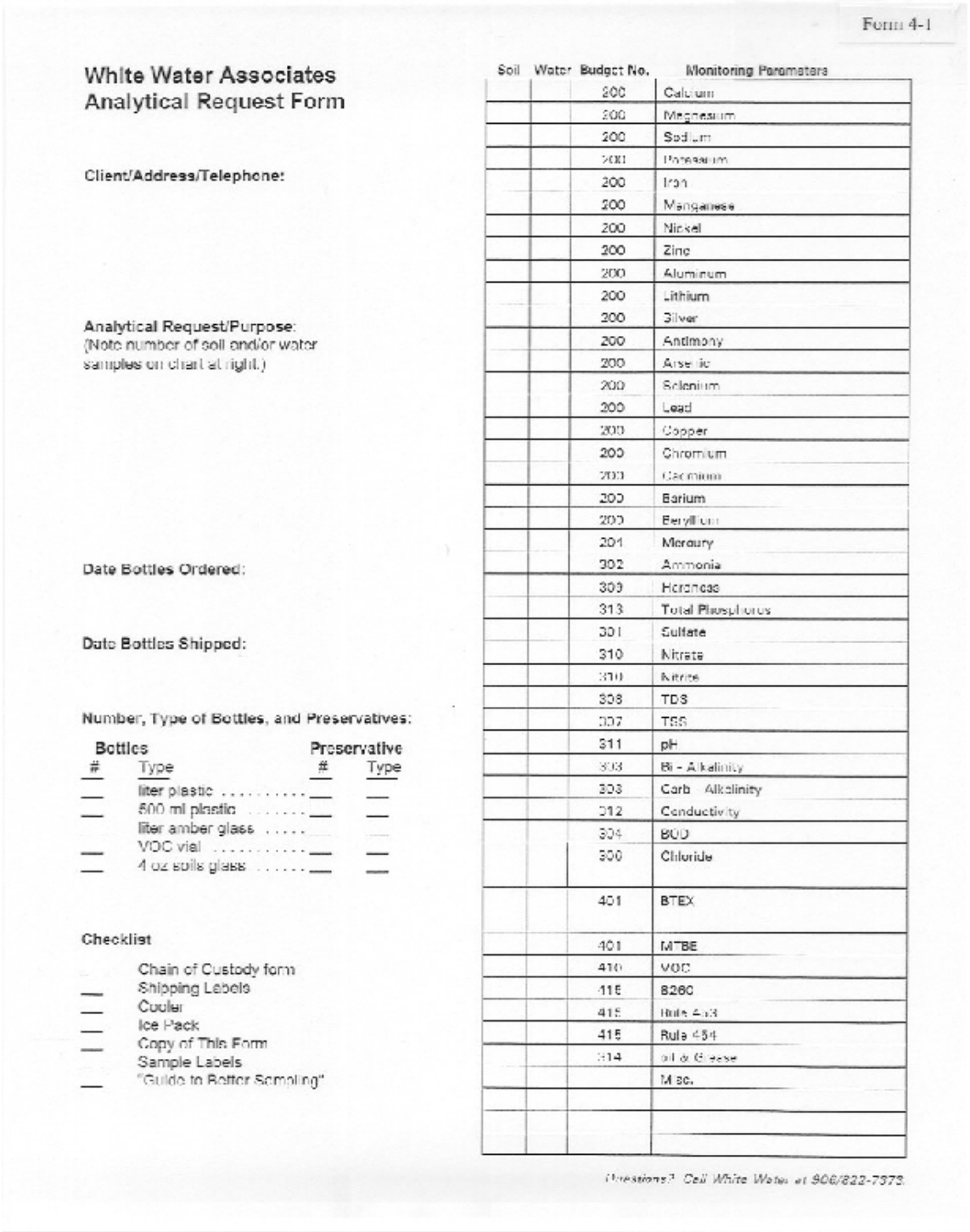
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Attachment A. Example of an analytical services request form



Form 4-1

White Water Associates
Analytical Request Form

Client/Address/Telephone:

Analytical Request/Purpose:
(Note number of soil and/or water samples on chart at right.)

Date Bottles Ordered:

Date Bottles Shipped:

Number, Type of Bottles, and Preservatives:

Bottles #	Bottles Type	Preservative #	Preservative Type
___	liter plastic	___	___
___	500 ml plastic	___	___
	liter amber glass		
___	VOC vial	___	___
___	4 oz soils glass	___	___

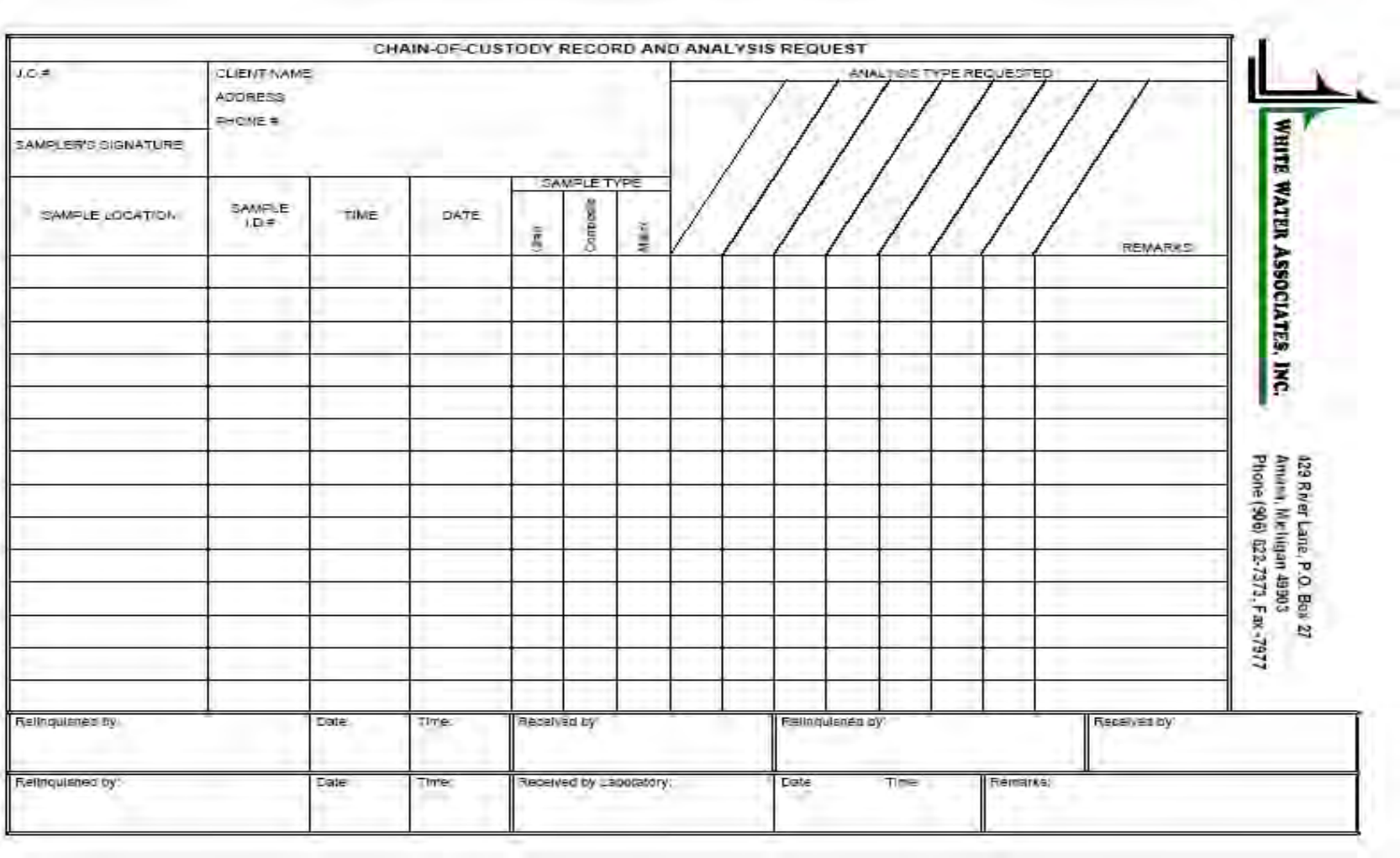
Checklist

- Chain of Custody form
- ___ Shipping Labels
- ___ Cooler
- ___ Ice Pack
- ___ Copy of This Form
- Sample Labels
- ___ "Guide to Better Sampling"

Soil	Water	Budget No.	Monitoring Parameters
		200	Calcium
		200	Magnesium
		200	Sodium
		200	Potassium
		200	Iron
		200	Manganese
		200	Nickel
		200	Zinc
		200	Aluminum
		200	Lithium
		200	Silver
		200	Antimony
		200	Arsenic
		200	Selenium
		200	Lead
		200	Copper
		200	Chromium
		200	Cadmium
		200	Barium
		200	Beryllium
		201	Mercury
		302	Ammonia
		309	Hardness
		313	Total Phosphorus
		301	Sulfate
		310	Nitrate
		300	Nitrite
		308	TDS
		307	TSS
		311	pH
		303	Bi - Alkalinity
		303	Carb Alkalinity
		312	Conductivity
		304	BOD
		300	Chloride
		401	BTEX
		401	MTBE
		410	VOC
		415	8260
		415	Rule 4-93
		415	Rule 434
		314	Oil & Grease
			Misc.

Questions? Call White Water at 906/822-7373.

Attachment B. Example of a chain of custody and analysis request form.



CHAIN-OF-CUSTODY RECORD AND ANALYSIS REQUEST

J.O.#

CLIENT NAME:
ADDRESS:
PHONE #:

SAMPLER'S SIGNATURE:

ANALYSIS TYPE REQUESTED

SAMPLE LOCATION	SAMPLE I.D.#	TIME	DATE	SAMPLE TYPE: Grab	Composite	Matrix								REMARKS

Relinquished by:	Date:	Time:	Received by:	Relinquished by:	Received by:

Relinquished by:	Date:	Time:	Received by Laboratory:	Date	Time	Remarks:

WHITE WATER ASSOCIATES, INC.

423 River Lane, P.O. Box 27
Amasa, Michigan 49903
Phone (906) 822-7373, Fax -7977

Standard Operating Procedure #8: Data Entry and Management

Version 1.0

In **Water Quality Monitoring Protocol for Inland Lakes**

Prepared by
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Figure 2. Great Lakes Network folder structure 8

Revision History Log

The following table lists all edits and amendments to this document since the original publication date. Information entered in the log must be complete and concise. Users of this standard operating procedure will promptly notify the project manager and/or the Great Lakes Network (GLKN) data manager about recommended and required changes. The project manager must review and incorporate all changes, complete the revision history log, and change the date and version number on the title page and in the header of the document file. For complete instructions, please refer to Revising the Protocol, SOP #13.

Revision History Log:

Previous Version #	Revision Date	Author (with title and affiliation)	Location in Document and Concise Description of Revision	Reason for Change	New Version #
Add rows as needed for each change or set of changes tied to an updated version number					

Acknowledgements

Primarily, we relied on the Great Lakes Network's data management plan (Hart and Gafvert 2005) in writing this document. Standard operating procedures for the entry and management of data written by other networks also provided guidance.

8.0 Introduction

Water quality data collected under the inland lakes water quality monitoring protocol (Elias et al. 2008) must be entered, quality-checked, documented, managed, and made available to others for a variety of purposes, such as management decision-making, research, and education. The National Park Service (NPS) Water Resources Division (WRD) developed a database application called the Water Quality Database Template, or NPSTORET, to facilitate management of water quality data. NPSTORET allows importing of water quality data into the National STORET (STOrage and RETrieval) Data Warehouse administered by EPA, as required by the water quality component of the Natural Resource Challenge (NPS 1999).

This standard operating procedure outlines data stewardship responsibilities and provides specific instructions and references for entering, quality checking, and managing water quality data.

8.1 Data Stewardship Roles and Responsibilities

The purpose of data stewardship is to share the responsibility for managing data and information resources that are organized, useful, compliant, available, and safe. The demand for detailed, high quality data and information about water quality requires a group of people working together to ensure that data are collected using appropriate methods, and that resulting datasets, reports, maps, and other derived products are well-managed.

The Great Lakes Network (GLKN) aquatic ecologist serves as project manager for water quality monitoring. The project manager will supervise data collection, provide project oversight, direct on-the-ground data collections, and provide cohesive links among data collection, synthesis, interpretation, and reporting.

While the project manager must act as the steward for water quality monitoring data for the Network, other project and GLKN personnel are also accountable for specific data management tasks. Table 1 lists stewardship responsibilities of personnel involved in the management of water quality data. To ensure that all project data are managed properly, individuals must understand their responsibilities, communicate with one another, and assist one another as needed.

8.2 NPSTORET Database

Water quality data are managed according to guidelines from the NPS Water Resources Division. In accordance with these guidelines, the desktop database application NPSTORET, also known as Water Quality Database Templates, will be used to enter, store, document, and transfer water quality data. The GLKN oversees the use of NPSTORET per the Network's water quality monitoring protocols and ensures that data are transferred at least annually to the NPS Water Resource Division for upload to the STORET database (Figure 1).

STORET is an interagency water quality database developed and supported by the Environmental Protection Agency (EPA) to house local, state, and federal water quality data collected in support of managing the nation's water resources under the Clean Water Act. NPS Director's Order 77 indicates that the NPS should archive water quality data in STORET, and the NPS WRD mandates that any data collected as part of a WRD-funded project get archived in STORET. The NPS uses STORET as a repository of physical, chemical, biological, and other monitoring data collected in and around national park units by park staff, contractors, and cooperators. The NPS operates its own Service-wide copy of STORET and makes periodic uploads to the EPA STORET National Data Warehouse so that data collected by and for parks will be accessible to the public.

Table 1. Data stewardship responsibilities of water quality monitoring personnel.

Personnel Role	Data management responsibilities related to water quality monitoring
Project Crew Member	Crew members collect and manage data with direction and guidance from the crew leader and/or project manager. Data collection includes calibrating and operating sampling equipment, collecting water samples, and recording measurements and observations. Crew members are responsible for quality control by following data collection and recording instructions and by promptly verifying recorded data. Crew members may also perform data entry and verification.
Project Crew Leader	The crew leader normally performs the same duties as the other crew members and ensures adherence to data collection and processing protocols, including data verification and documentation. The crew leader also works with the project manager and data manager on water quality data management in the office.
Project Manager (Network Aquatic Ecologist)	The project manager is responsible for all project operations and results, and may also participate in field operations. The project manager ensures that data management activities are conducted according to established procedures and is responsible for data validation: approving the data content, quality, and documentation, as well as making decisions about data sensitivity and distribution. The project manager is responsible for evaluating project data at specified intervals, analyzing data for trends, and following reporting requirements.
Resource Specialist	The water resource specialist, who may also serve as a crew leader, works closely with the project manager in all aspects of data management. The water resource specialist collects field data, enters field and laboratory data, verifies data, and validates data.
Network Data Manager	The network data manager, together with the project manager, ensures that water quality monitoring data are organized, useful, compliant, available, and safe. The network data manager provides the most current version of NPSTORET and works with project personnel to ensure Network water quality data are received by WRD. The network data manager oversees activities related to training, user support, quality assurance, documentation, backups, archiving, and data maintenance and distribution.

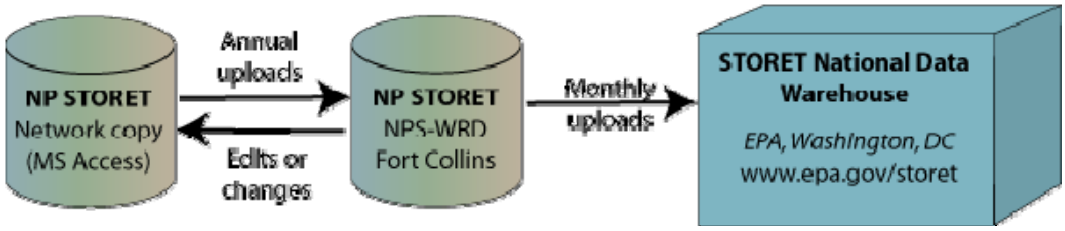


Figure 1. Schematic of data flow: water quality data are transferred from the Network to the national master database and ultimately to the master database. Public access to STORET is available via an on-line clearinghouse.

8.2.1 Database Design

The database design for NPSTORET is described in its associated documentation. Because it must be compatible with the Oracle-based EPA STORET, NPSTORET is a complex MS Access implementation. The latest version of NPSTORET can be found at: http://nrdata.nps.gov/programs/water/npstoret/

GLKN has a number of different avenues for data distribution depending on the audience served and the degree of analysis and customization needed by the end-user (see GLKN's data management plan, Hart and Gafvert [2005], for more details). One of the primary methods GLKN uses for data distribution is the Vital Signs Internet Mapping Service (VSIMS) that allows users to explore and query monitoring data using spatial and non-spatial parameters. Network (GLKN) versions of NPSTORET are used to update a master version of STORET maintained by NPS WRD. The WRD master copy of STORET data is the data source that is used by the VSIMS to serve water quality data collected by GLKN and other I&M networks.

The Great Lakes Network will maintain one master copy of NPSTORET for each park at the Ashland office on a central server. This is the only copy of NPSTORET that can be used to export data to other locations (i.e., WRD and GLKN's SQL Server). Additional copies of NPSTORET can be used by GLKN personnel stationed at parks, but they can only be used as a conduit for data entry and the importation of data to GLKN's master version of NPSTORET. For analysis, the data from the master copy of NPSTORET, that has passed all QA/QC procedures, must be used.

8.3 Data Management Procedures

8.3.1 Data Collection

Data values are measured, observed, or estimated according the GLKN inland lakes water quality monitoring protocol at various monitoring locations (sample sites) and recorded on field forms (see SOP #6, Field Measurements and Water Sample Collection). Crew members are responsible for legible, accurate entries on field forms and in log books, including the calibration

log. As a first step to verify data, crew members will check and double-check the recorded values on the day of data collection.

Data collected with a multiparameter sonde are stored directly on a datalogger attached to the sonde and recorded on the field sheets at the time of sampling. The hard copy of the data serves as a back-up should something happen to the electronic data.

Digital images of sample sites are acquired during site establishment and periodically as sites change (SOP #6). Crew members are responsible for proper settings and use of digital camera equipment and should refer to the user manual for details specific to the camera.

GPS coordinates are stored as waypoints if using a recreational GPS unit, or as features if using a mapping-grade unit with a data dictionary, and recorded on the field sheets. When possible, the GPS data will be differentially corrected to improve the accuracy of location coordinates. See SOP #3 for more information on using a GPS unit.

Water samples are collected, labeled, and packaged for laboratory analysis according to SOPs #6 and #7. Identification numbers on sample containers, chain of custody forms, laboratory reports, and on the field data collection form facilitate management of laboratory results.

8.3.2 Data Entry, Verification, and Documentation

Requirements for data entry into NPSTORET are detailed in the documentation for users. We present a summary of data entry below, and refer staff to the most recent NPSTORET documentation for the specifics.

On a regular schedule approved by the project manager and data manager, the crew leader gathers the field data collection forms and verifies the completeness, accuracy, and legibility of each form. Following each round of sampling, the crew leader will make a photocopy of each field form and ensure each copy is legible; the copy will be placed in the office binder kept at the park, and the original will be sent to the project manager for archival in the GLKN office. Additional photocopies will be made as needed. Upon receiving the original data sheets, the project manager will proofread the datasheets, making sure that they have been filled out completely. All data sheets should have been reviewed for completeness while in the field, however some deficiencies in data recording may not be identified until all data sheets have been reviewed as a group.

Electronic data from the multiparameter sonde are downloaded from the datalogger to a computer in an MS Excel spreadsheet or text file at the end of each sampling day or as soon as feasible after sampling, and verified for accuracy. Likewise, at the end of each sampling day or as soon as feasible after sampling, all digital images will be downloaded to a computer and labeled with date, location, and subject matter. Both of these types of electronic data will then be imported into NPSTORET.

Project staff enters site establishment data in the NPSTORET Station Entry Template as soon as possible following the initial site visit to each sample location. This prompt action is a good data

management practice and an NPSTORET requirement that enables parameter data entry. Linking digital images of sample sites to stations in NPSTORET is required as part of this data entry process.

File size for digital images linked to stations in NPSTORET should normally be at least 100kb and less than 300kb. Project staff will reduce the size of image files larger than 300kb and copy images to a file folder named "images" for the appropriate park. Original 'raw' images can be stored in the Images folder (see Folder and File Organization below) if project staff determine it is important to keep higher resolution images.

Import data from the MS Excel spreadsheet into NPSTORET following the guidelines. Any notes taken in the field regarding collection of data with the sonde are transcribed to NPSTORET in a field for comments and notes.

Results of laboratory analyses typically are sent to the project manager in a MS Excel spreadsheet and on hard copy forms. The project manager will verify both sets of data and follow-up with the contract laboratory if any discrepancies are noted or any questionable results are reported (see SOP #12 on QA/QC for more details). Project staff will import the verified data into NPSTORET.

On a regular schedule approved by the project leader and data manager, project staff will enter the verified field data from both hard copy and data logger in NPSTORET. Several times each season the project leader will perform or coordinate a random spot check of ten percent of the characteristic values entered in NPSTORET that season. The project leader resolves errors according to established procedures. See SOP #12 for additional QA/QC details.

Data verification starts with the QA/QC steps that are detailed in SOP #12. As data are entered into NPSTORET, either by keyboard or using an import routine, a suite of QA/QC procedures exist that compare the entered data with expected formats and accepted data value ranges or domains. If the entered data do not pass a form-based QA/QC test, NPSTORET prompts the user to make corrections and re-enter the data. For most of the form-based tests, the NPSTORET database will not accept out-of-bounds data, and correction is mandatory; for some range tests, out-of bounds data are accepted after a user prompt, but are flagged accordingly. The QA/QC procedures on imported data perform similar tests, but exceptions that do not pass QA/QC are presented to the user and must be reconciled before the record or dataset can be accepted by NPSTORET.

Additional comparison tests will be run on data in NPSTORET to flag records that are outside the expected rate of change for a parameter based on previous records for that parameter. These suspect data points are reviewed by an expert user and can be corrected, flagged, or excluded from the dataset.

As mentioned above, NPSTORET performs numerous QA/QC checks on the data as they are entered and stored. Additionally, once the data are transferred to WRD, more QA/QC procedures are performed. The Network's water quality data records are regarded as being in provisional status until they are returned to GLKN from WRD, or are accepted by WRD without changes after the final QA/QC steps. Each individual record in the water quality dataset always has one,

and only one, status flag indicating its status as provisional or final. Finalized data can still be edited and changed if errors are discovered after review in reporting and analysis, but the status of those records reverts to provisional and they must be resubmitted to the master STORET version at WRD and returned before they can be reassigned as finalized data records.

A user's identification is assigned to each aspect of data handling, from collection through the final steps of QA/QC. On data sheets, the identity of the data collector(s) is recorded and is transcribed into the data entry forms in NPSTORET. Additionally, NPSTORET records the user name (login) for every table entry or modification. Only qualified users who have been trained and given edit permissions are allowed to edit data in NPSTORET. These procedures protect the integrity of the data and allow the history of each data record to be traced.

Executive Order 12906, mandates federal agencies to "...document all new geospatial data it collects or produces, either directly or indirectly..." using the Federal Geographic Data Committee Content Standard for Digital Geospatial Metadata. Water quality monitoring meets the definition of geospatial data and, thus, GLKN is responsible for documenting all public datasets using metadata that meets that standard. NPSTORET requires and stores a great deal of metadata at the record and project level. Metadata will be developed, using NPSTORET as a primary source, that meets the federal standard. Consult the GLKN Data Management plan (Hart and Gafvert 2005) for additional details about meatdata procedures and requirements.

8.3.3 Data Validation

Prior to distributing the data for any type of use, the project manager or other appropriate water resource specialist validates the NPSTORET database content in the master water quality data file according to procedures in the Quality Control and Quality Assurance SOP. The integrity of each master data file must be preserved during the validation process in cases where the person performing data validation does not have direct access to the master water quality data file. Validation is performed at least once each year after data collection and entry are complete and before data are submitted to the NPS Water Resource Division, usually by the end of each calendar year. If this annual validation does not meet scheduled reporting requirements of the Network, then the project manager may coordinate more frequent validation to meet needs, or reports can include a statement explaining that results are based on data that have not been validated. The statement should include an explanation of what significance this has for using preliminary data.

Laboratory results must be entered and validated in NPSTORET as soon as possible following receipt of the results. The project manager coordinates receiving and entering data with project staff and then performs or coordinates the validation of lab results.

8.3.4 Data Analysis and Reporting

Project staff will follow the procedures for data analysis in SOP #9 and data reporting in SOP #10. Data summary statistics will typically include, but not be limited to:

- Mean
- Median
- Standard deviation
- Minimum
- Maximum
- Count
- Percentiles (10, 25, 75, and 90th percentiles)
- Standard error
- Variance
- Range
- Mode
- Sum
- Kurtosis
- Skew

Some of these statistics are available through NPSTORET's query function and others can be derived from NPSTORET outputs. NPSTORET provides an export for any portion of the data in tabular format for use with the Data Analysis Toolpak.

8.3.5 Data Folder and File Organization

All data from this water quality protocol should be stored, at the earliest possibility, on the GLKN central server. A diagram showing the folder structure is shown below (Figure 2).

Files should be named in accordance with the file-naming standards in the GLKN Data Management plan (see section 6.4 of Hart and Gafvert 2005). Files have a 'GLKN' prefix, a descriptive element, and finish with a date element. For example, GLKN_ ISRO_Field_Data_20070605.doc contains field data from Isle Royale National Park on June 5, 2007. Do not use spaces in file names.

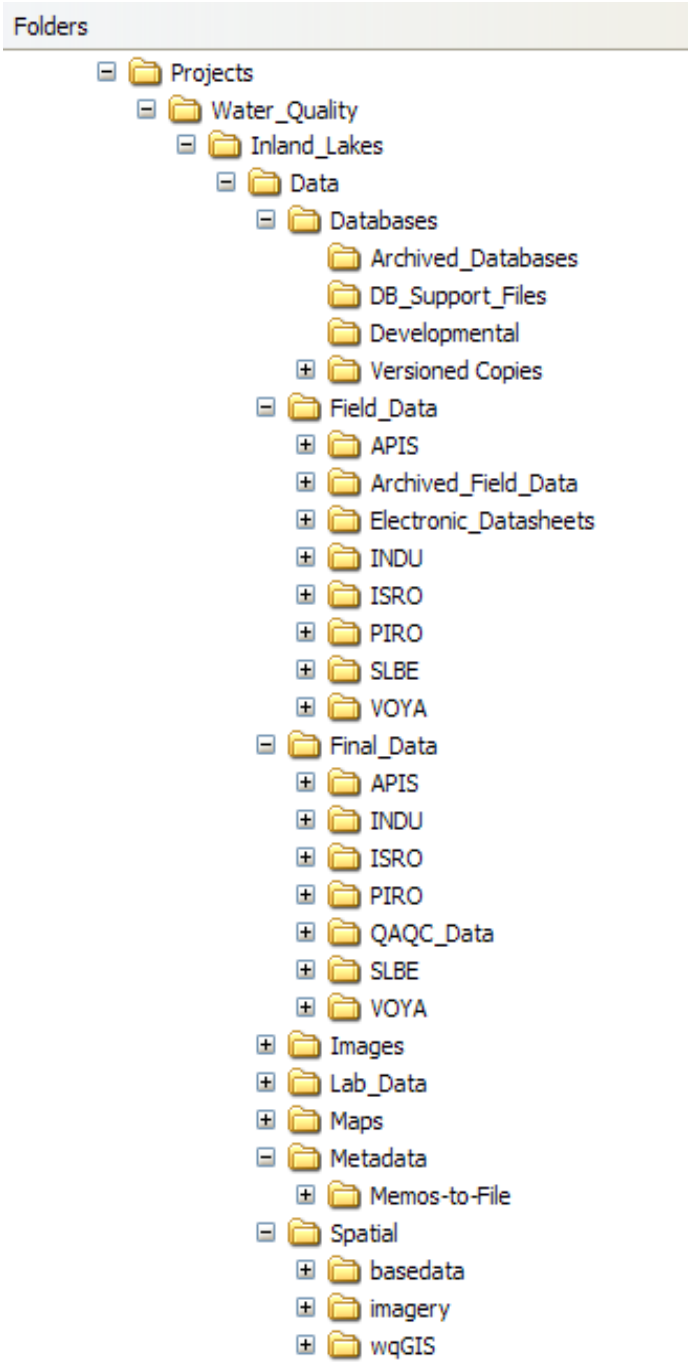


Figure 2. Great Lakes Network folder structure for information related to the protocol for monitoring water quality of inland lakes. The Images, Lab_Data, and Maps folders also have subfolders for each park. Data are organized in subfolders by year within each park folder.

8.3.6 Data Archival and Distribution Procedures

Data archiving serves two primary functions: it provides a source to retrieve a copy of any data set when the primary dataset is lost or destroyed, and it provides a data record that is an essential

part of the QA/QC process. Original data will be archived at the Network office. Original data for printed forms are either the physical datasheets or exact and complete digital copies of the forms that capture all entries and notations. The unedited files are the original data for digital data.

All digital data have a duplicate file created at the earliest opportunity. At least two complete copies of any water quality dataset are required by WRD, including digital replicas (scanned versions), if they are created, of hard copy data sheets. Digital field data that are entered directly into a field computer or collected from a data logger must be backed up to a second medium at the earliest possibility. The data files on field computers and loggers must not be erased until the integrity of these data files are verified on the duplicate storage medium. The removal of original data files from a field computer or logger must be a balance of keeping memory available for new data collection and a need to keep data in their most original form for as long as possible. Field files should only be deleted when memory space is needed for new data collection.

The Network's master version of NPSTORET and the SQL Server geodatabase are maintained on a central server in the Ashland Office that is backed up daily, and backed up off-site weekly. Complete details of the GLKN Server archiving procedure are found the Infrastructure chapter of GLKN's Data Management Plan (Hart and Gafvert 2005); the general strategy for data archiving is also described in this plan and its appendices.

Public distribution, as well as long-term archival of water quality data, is provided by the NPS WRD STORET database and the National EPA STORET Data Warehouse and their associated online interfaces. As stated above, the Network will send its master version of NPSTORET to WRD at least annually. In cases where more recent data are requested, the project manager or appropriate water resource specialist will respond based on the nature of each request and the state of the data, for example, whether or not the data are fully qualified and documented to meet the needs of the requestor.

8.4 Literature Cited

Elias, J. E., R. Axler, and E. Ruzycki. 2008. Water quality monitoring protocol for inland lakes, Version 1.0. National Park Service, Great Lakes Network, Ashland, Wisconsin. Natural Resources Technical; Report NPS/MWR/GLKN/NRTR—2008/109. National Park Service, Fort Collins, Colorado.

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Standard Operating Procedure #9: Data Analysis

Version 1.0

In **Water Quality Monitoring Protocol for Inland Lakes**

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9.0 Introduction

Data analysis is the process by which measurements of the environment are interpreted meaningfully. It begins with evaluations of data after the data have been collected and entered into an electronic file or database, and have undergone a check of the data entry to ensure quality. Data analysis includes quality assurance/quality control (QA/QC) checks for statistical outliers prior to data summarization, may include exploratory data analysis, and concludes with analyses that lead to summary and interpretations of the data.

Well-conceived and -developed monitoring strategies have clear connections between questions of interest, appropriate sampling designs, and resulting analytical approaches (Noon 2003). Accordingly, the utility and robustness of the Great Lakes Network's (GLKN) analyses for monitoring water quality are based on ecologically meaningful questions and relationships, which prescribe the monitoring design, which in turn prescribes an analytical approach. Increasingly, biometricians are advocating that ecologists seek to elucidate and quantify ecologically important phenomena, rather than exclusively pursue statistical significance (Yoccoz 1991, Johnson 1999, Anderson et al. 2001). Efforts of GLKN to monitor water quality seek to provide a quantitative understanding of the effect size (e.g., temporal trend, difference in indicator values among pre-defined strata) as well as the repeatability of that result (i.e., a measure of precision or uncertainty associated with the estimate). We are striving to address directed monitoring questions that reflect our prior knowledge of the system and may provide useful information for management decisions, rather than test myriad hypotheses about ecosystem change.

In addition to quantitatively describing the status and temporal trends of water quality indicators, a secondary goal is to begin to understand the dynamics and drivers of our indicators, following our conceptual models (Gucciardo et al. 2004). Although not every trend is a product of local management action, tests of association that address the underlying 'why' questions behind the 'what' questions in trend analysis will be explored for at least a subset of our metrics of water quality. Although the validity of these associations can be strengthened with focused research, these types of questions increase the likelihood that our monitoring can lead to an early correction of trend before the cascading ramifications become irreversible.

9.1 Temporal and Spatial Domains

As described in the protocol narrative for monitoring water quality in GLKN inland lakes (Elias et al. 2008), we have defined our temporal domain as daytime periods during the ice-free months, ideally, when lakes are thermally stratified. Selected lakes will be sampled three times annually, at the same location within each lake. We selected lakes using several criteria, including lake type based on ordinations of past chemistry data to determine groupings of similar lakes within a given park, amount of past data, spatial balance within each park, and particular interest by park staff. We also selected lakes to span various gradients within a park, such as gradients across intensity of visitor use, surface area, maximum depth, and watershed area. Sampling of lakes typically occurs at the deepest location of a given lake unless a question specific to the littoral zone is being addressed. It has been shown that spatial variation within a basin is small relative to temporal variation (Hanna and Peters 1991, Marshall and Peters 1989)

for highly variable parameters such as chlorophyll and phosphorus. Therefore, we will maximize the number of sampling visits per lake, within budget constraints, and sample at a single location (the deepest part of the basin).

9.2 Initial QA/QC Checks for Outliers in Data

All water quality data undergo several quality assurance/quality control (QA/QC) procedures (e.g., duplicate sampling, data-entry filters, removal of logically inconsistent entries; see SOP #8 for data management details) to ensure that the data accurately represent the natural environment at the time of sampling. In addition to these procedures, several analytical and data sorting techniques (e.g., scatter plots, box-and-whisker plots, stem-and-leaf plots, sorting values of a given indicator in ascending or descending order, "COUNTIF" statements in Excel) are available to identify potentially erroneous values and statistical outliers. During this process, data points that do not meet limitations for precision or bias may be flagged or eliminated from the database. Some statistical measures, such as population mean, are sensitive to extreme atypical values, or outliers. Therefore, to reveal the central tendency of the population, the project manager may elect to remove outliers from the data pool. Such removals should be performed with great caution, and only when it is clear that the outlier truly did not reflect system properties (e.g., the outlier resulted from instrument error, transcriptional error, contamination of the sample).

9.3 Annual Data Summaries

Brief characterizations of the data from each lake, each park, and the Network as a whole will be performed each year, after all QA/QC procedures have been completed. For each lake sampled, and for each parameter measured, descriptive statistics will include mean, median, maximum and minimum values, as well as skew, kurtosis, and measures of variability, when appropriate (e.g., coefficient of variation, standard error, variance).

Given the relevant legislation (e.g., Clean Water Act of 1972), it may be of interest to individual NPS units and to other entities to assess the proportion of measurements during a time period or across a domain (at a single point in time) that exceed pre-determined thresholds, such as State water quality standards or ecoregional nutrient criteria. As with nearly all percentage data, arcsine transformations must be performed on those data before statistical analyses can be conducted (Sokal and Rohlf 1995).

9.4 Analyses of Long-Term Trends

In addition to these descriptive statistics, analytical approaches may also include estimation of interannual change, graphic approaches (e.g., comparison of mean and variability of a parameter in the current year versus during past years), and occasionally qualitative analysis (Guthery et al. 2001), as well as modeling, correlational analyses, and various parametric and nonparametric analyses. Results of such analyses will be distributed via synthesis reports and/or articles in peer-reviewed journals.

Because lakes were not selected randomly, we will not make inferences about trends in lakes

other than those we sample. We will analyze data from each lake independently of all other lakes. All lakes sampled within a park may be grouped for analytical comparison with lakes sampled in another park. Whenever lakes are pooled for analysis, we will ensure inferences are not made beyond those lakes that were sampled. Characteristics of the lakes that are known or suspected to affect water quality (e.g., lake size, maximum depth, underlying geology, watershed characteristics) can be included as covariates.

9.4.1 Recommended Methods for Long-Term Trend Analysis

Synthesis reports will include more intensive analyses of change after at least three years of sampling in a given lake has occurred. In addition to repeated-measures, time-series, regression, and non-parametric equivalents of various methods (such as regression, paired-*t* tests, and ANOVA), monitoring data may also be evaluated through nonparametric trend tests (e.g., Mann-Kendall or Seasonal Kendall), Monte Carlo simulation analyses, Bayesian analyses, and comparisons of period means. For the latter-most approach, one is often interested in comparing values before and after an important event (e.g., change in management policy, remarkable anthropogenic disturbance, natural catastrophe, drought), and considers years within each of the two periods as replicates. We may also examine trends for breakpoints, or changes in slope, which may indicate the timing of an important event, and hence a potential cause. Trends in parameters that are analyzed with respect to biotic and abiotic covariates will be included in the synthesis reports, although cause-effect relationships may be investigated more thoroughly by NPS partners and collaborators.

In addition to analyzing each variable separately, water quality variables could be analyzed collectively through multivariate ordinations (e.g., nonmetric multi-dimensional scaling) of resource conditions through time, following West and Yorks (2002). This approach effectively integrates information across many indicators, and can suggest whether individual stations are all moving in the same direction in multidimensional ordination space. Furthermore, joint plots can be overlaid on the ordination, and can suggest which variables correlate most strongly to the direction of changes. Similarly, if specific comparisons are desired across a suite of uncorrelated variables, two or more pre-defined groups of samples could be compared using MANOVA or NPMANOVA, depending on whether parametric assumptions are met.

9.4.2 Approaches to Analyze Frequently-Collected Data

In contrast to many other parameters that the Network is monitoring, water quality measurements are collected several times per year. Not only does the long-term nature of this data set allow for robust retrospective analyses of trend, but the multiple sampling sessions within each year allow for various analytical approaches to analyze long-term trends. For example, if the goal is to monitor trend in the *average* value of a particular water-quality parameter, then all measurements collected within the year (or during the ice-free season) at each sampling location would be considered temporal subsamples and averaged. Trend analysis (using repeated-measures, time-series, or other regression analyses) would thus be performed simply on the annual means at each sampling location. This approach seems particularly viable for parameters that do not exhibit strong intra-annual variability (e.g., pH). However, this approach may be vulnerable to imprecision or bias if a parameter exhibits significant, predictable variability in its value

throughout the year and data are not collected (due to equipment failure or logistical constraint) at a high number of intended sampling occasions.

Alternatively, if a particular parameter is known to exhibit significant intra-annual variability (e.g., chlorophyll-*a*), samples within the year can be partitioned into one of several periods (ideally, defined by relevant phenological or biological phenomena). Thus, for example, if interannual trends in nutrient concentrations during algal blooms are of interest, the temporal domain can be accordingly defined, and all samples within that window averaged within each year and the means analyzed for trend across years. Finally, if there is a strong desire to incorporate intra-annual variability into interannual trend analyses, data within each year can be analyzed through a smoothing algorithm, and interannual variability is thus analyzed on the smoothed data. It may be the case, however, that process variation is larger than the sampling variability (Burnham et al. 1987).

9.4.3 Duplicate Sampling

To ensure that understanding of water quality trends within lakes of the GLKN is not confounded by biased results, we will collect duplicate samples and field measurements at the rate of approximately once every 10 samples. We will assess the relative percent difference between duplicate samples or measurements and flag data that do not meet the QA/QC guidelines detailed in SOP #12. Those data that do not meet the QA/QC stipulations may or may not be used in analyses, on a case by case basis. For example, parameters measured at low concentrations (e.g., less than five times the method detection limit) may be accepted, and both duplicates used in analysis. If duplicate samples meet the QA/QC guidelines, we will use the mean value of the duplicate measurements in data analyses. Explanations of how duplicates are handled in data analyses will be included in reports.

9.4.4 Other Analytical Considerations

For trend analyses performed using regression, trend will be investigated using a linear relationship. If analyses suggest a non-linear temporal pattern, serial autocorrelation, or lagged response to stressors, appropriate analytical modifications will occur. When discussing the desire to be able to detect a trend of 20%, for example, it must be stated *during what time period* that level of change is to be detected. This allows one to calculate the minimum level of change that is important to detect between successive sampling periods. A 20% change occurring over 1 year is obviously much different than that same level of change (20%) occurring over 10 years (i.e., an average change of 1.84% per year).

Adopting the philosophies of the precautionary principle (United Nations 1992) and the safe minimum standard of conservation (Ciriacy-Wantrup 1952, Berrens et al. 1998), the GLKN monitoring program seeks to identify potential natural resource problems early, before deleterious or irreversible ecosystem changes occur (e.g., crossing of ecological thresholds; Laycock 1991, van de Koppel et al. 1997, Laurance and Williamson 2001). Consequently, for most analyses that use the null hypothesis of no change through time, we will adopt $\alpha = 0.10$. Furthermore, for parameters that exhibit particularly high variability, magnitudes of change that seem biologically meaningful (Johnson 1999) yet have $0.10 < \alpha < 0.20$ may merit more intensive

or extensive monitoring or experimental study.

If water quality monitoring tracks a relatively large suite of variables, Bonferroni or modified Bonferroni corrections (e.g., Hohm's method) may be performed, to maintain the 'familywise' alpha at 0.10. Roback and Askins (2005) argue that if the main goal is simply initial screening for conservation problems or generation of hypotheses to be tested further, but not detection of real differences or trends, then alpha can be left at its standard comparisonwise significance level, to avoid Type II errors.

When the dataset contains non-detects, we will follow Helsel (2005) in conducting statistical analyses. Several methods exist for handling non-detects, each with advantages and drawbacks. Early in our program we will likely use a substitution method, where a value between zero and the detection limit will be substituted for the non-detect. The main drawback of this method is that estimates of the true variability are not possible. When the program is more mature and we have adequate data to determine the distribution of data, we will likely use maximum likelihood estimation, which works well for large sample sizes. Other methods, such as "regression on order statistics" and the non-parametric Kaplan-Meier method will be considered, and in consultation with a statistician, the most appropriate method for the data will be employed.

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Standard Operating Procedure #10: Reporting

Version 1.0

In **Water Quality Monitoring Protocol for Inland Lakes**

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10.0 Introduction

A primary goal of the NPS Servicewide I&M Program is to ensure that the results and knowledge gleaned from monitoring are shared with all appropriate parties, especially the parks and their natural resource managers. Because the Network's main focus is to assist parks with monitoring needs, we will strive to provide park managers with clear, meaningful products to convey our findings.

While the Network primarily addresses concerns of the parks, its monitoring program has the potential to serve a much broader community. For example, monitoring projects can provide a starting point for external scientific research (especially to establish cause-effect relationships), and can provide insights for adaptive management on other public lands. The Network is also accountable to multiple organizations within the federal government, including the NPS I&M Program and the U.S. Congress. To ensure accountability and to meet the requests of all parties, we will provide the types of reports and communications detailed below.

10.1 Annual Summary Reports

A summary report will be produced annually for the inland lakes water quality Vital Signs monitored during the previous year. The primary audience for the annual summary reports will be parks. These summaries will be communications to document our efforts and convey the findings of the previous field season. At a minimum they will provide:

- a brief introduction that describes why that Vital Sign is being monitored;
- an outline of the sampling strategy, including the number of sites sampled, parameters measured, and analyses performed;
- data summaries, including tables and figures to enhance visual presentation, as well as a text explanation of the findings;
- any other relevant or significant findings; and
- a limited discussion section in which important results are interpreted.

The project manager (aquatic ecologist) will take the lead in writing the report and will coordinate an internal review. The reports will be provided to parks as soon as possible following the completion of each field season.

10.2 Analysis and Synthesis Reports

Detailed reports in which data are analyzed and synthesized will be produced on a periodic basis, with the frequency depending on the given Vital Sign. The first analysis and synthesis reports will be written after at least three years of water quality data have been collected at a given park. The frequency of subsequent detailed reports will depend on the data and whether or not trends seem to be occurring. As lakes at the parks are monitored repeatedly, in-depth analyses will be conducted for each park as well as across parks.

The reports will be written in the format of a scientific journal article (abstract, introduction, methods, results, discussion, literature cited) and will contain in depth analyses as outlined in the protocol narrative and SOP #9, Data Analysis. Further, these comprehensive reports will:

- place the observed results in both a regional and historical context by relating them to other published literature;
- discuss the significance of the results in terms of environmental change; and
- provide management recommendations based on the findings.

The project manager will take the lead in writing the analysis and synthesis reports, and will coordinate an internal review. The target audience of these reports will be the parks (primarily the natural resource managers), the Network, and both regional and Servicewide I&M. Outside of the park service, the target audience includes the four state departments of natural resources (Indiana, Michigan, Minnesota, Wisconsin), the Minnesota Pollution Control Agency, the St. Croix River Interagency Basin Team, and the broader scientific community.

Drafts of analysis and synthesis reports will be reviewed internally and possibly sent to outside sources for further review, depending on how analytically complicated the methods are and on the gravity of the implications and recommendations..

10.3 Scientific Journal Articles

Because the inland lakes protocol has been designed with rigorous standards for sampling design and analysis, monitoring results are expected to be highly defensible and meet the standards of the peer-review process. The publication of monitoring results in scientific journals will allow the Network to reach the scientific community in a way that internal NPS reports cannot. Further, peer-reviewed publications can promote collaborative investigation by members of the scientific community, either independently or in cooperation with the Network. Ultimately, this process should foster a greater understanding of ecosystem components and processes.

For these reasons, the Great Lakes I&M Network will strive to publish analysis and synthesis reports in peer-reviewed scientific journals. We will encourage the preparation of manuscripts by having reviewers of analysis and syntheses reports recommend whether publication is warranted and suggest appropriate journals. The aquatic ecologist and Network coordinator will track these recommendations and encourage and provide work time respectively.

10.4 Other Communications

While reports are a definitive method of documenting the progress of each program, other means of communication can further disseminate information to a broader audience. To this end, we will provide the following additional types of communications:

Briefings to Park Biologists

The project manager will present the findings from the water quality monitoring program to the biologists from the parks in which monitoring was conducted the previous year. These

presentations, which will likely occur at the annual technical committee meeting in March, will provide a concise synopsis of monitoring results as well as management considerations.

Conference Presentations

When possible, the project manager will present monitoring results at regional and national scientific conferences. Such presentations will allow the Network to reach the broader scientific community, as well as land managers and conservation practitioners. Potential conferences include those sponsored by the Ecological Society of America, Society for Conservation Biology, The Wildlife Society, the Natural Areas Association, the NPS Water Professionals Meeting, and the George Wright Society. At a more local scale, the Western Great Lakes Research Conference, which is sponsored in part by the Network, is a valuable venue for information exchange.

Standard Operating Procedure #11: Post-Season Procedures

Version 1.0

In **Water Quality Monitoring Protocol for Inland Lakes**

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11.0 Introduction

The proper maintenance and storage of field and laboratory equipment will prolong the life of the gear as well as simplify start-up procedures for the next field sampling season.

11.1 End of Season Procedures

11.1.1 Field Instrumentation and Equipment

When multisensor water quality probes are to be stored for extended periods of time, make the following preparations:

- Thoroughly clean the sensors.
- Remove installed batteries.
- Fill the storage cap approximately one-fourth full of tap water. If the sensors might be exposed to freezing temperatures, use a solution of one-half tap water and one-half methanol.
- Store away from direct sunlight. Although the instrument should be able to be reliably reactivated for field use with a minimum of effort before field use, it should be checked out well in advance of scheduled surveys to allow time for repair or replacement.

Refer to equipment manuals for more detailed instructions regarding maintenance of multiprobe sondes.

End-of-season care of other equipment includes the following:

- Inspect and clean all equipment following the procedures detailed in SOP #5, Decontamination of Equipment to Remove Exotic Species. This effort minimizes the potential for transferring nuisance species from contaminated lakes to uncontaminated lakes.
- Lay out all ropes and sampling lines to dry completely, then coil or roll back into their holders.
- Store field equipment in protective storage cases to avoid damage.
- Clean all sample collection and storage containers in a 0.1N HCl acid bath followed by deionized water rinses as per SOPs #6 and #7.
- Return all of the equipment and supplies to the proper storage area. Keep them organized so they can be inventoried using the equipment and supply checklists.
- Store calibration standards and electrolyte solutions in a temperature-controlled environment.
- Properly dispose of all chemical waste material.

11.1.2 Laboratory Equipment

- Clean all labware in a 0.1N HCl acid bath followed by deionized water rinses as per SOP #7.
- Inventory all supplies and replace if necessary as soon as possible.

11.2 Data Management

There is no substitute for complete and accurate record keeping of field-derived data. Field technicians, crew leaders, and project leaders share responsibility for collecting, verifying, and documenting data according to the guidelines in this monitoring protocol and all applicable standard operating procedures. Refer to the GLKN Data and Information Management Plan (Hart and Gafvert 2005) for overall guidance and follow SOP #8, Data Entry and Management and SOP #10, Reporting, for additional details.

11.3 Quality Assurance/Quality Control

Taking proper care of all field and lab instrumentation and sampling gear is a fundamental part of any QA/QC program. Sensors that are properly cared for will likely be less variable and equilibrate more quickly in the field. See SOP #12 for additional details on QA/QC procedures.

11.4 Literature Cited

Hart, M., and U. Gafvert. Editors, 2005. Data management plan: Great Lakes Inventory and Monitoring Network. National Park Service Great Lakes Inventory and Monitoring Network Report. GLKN/2005/20.

Standard Operating Procedure #12: Quality Assurance/Quality Control

Version 1.0

In **Water Quality Monitoring Protocol for Inland Lakes**

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12.0 Purpose

This standard operating procedure (SOP) defines procedures for quality assurance and quality control to be used with the Great Lakes Network protocol for monitoring water quality in inland lakes. Quality assurance is the planned and systematic pattern of all actions necessary to provide adequate confidence, or assurance, that a project outcome optimally fulfills expectations. Quality control is the systematic evaluation of the various aspects of a project to ensure, or control, that the standards of quality are being met. Quality control involves specific tasks undertaken to determine the reliability of field and laboratory data. Together, quality assurance/quality control (QA/QC) is a substantial part of any monitoring program. The objective of QA/QC is to ensure that the data generated by a project are meaningful, representative, complete, precise, comparable, scientifically defensible, and reasonably free from bias (Irwin 2006).

12.1 Applicability

Procedures in this SOP will be implemented during all work pertaining to monitoring water quality in inland lakes as described in the protocol narrative. This SOP is designed to assure that all data obtained will contribute quality information to an understanding of the ecological integrity of park units of the Great Lakes Network.

The rationale for dividing a sampling protocol into a protocol narrative with supporting SOPs is based on the following:

- The protocol narrative is a general overview of the protocol that gives the history and justification for doing the work and an overview of the sampling methods, but does not provide all methodological details. The protocol narrative will only be revised if major changes are made, such as changes in sampling design.
- The SOPs are specific step-by-step instructions for performing a given task. They are expected to be revised more frequently than the protocol narrative.
- Usually, when a SOP is revised, it is not necessary to revise the protocol narrative to reflect the specific changes made to the SOP. All versions of the protocol narrative and SOPs will be archived.

The steps for changing the protocol (either the protocol narrative or the SOPs) are outlined in Procedures for Revising the Protocol (SOP #13).

12.2 Summary

Inland lakes are important and valuable resources at six of the parks of the Great Lakes Network (APIS, INDU, ISRO, PIRO, SLBE and VOYA). Lakes at these parks are used extensively by visitors for fishing, boating, swimming, and other recreational activities. The preservation of lake water quality and quantity is of utmost importance to park managers, researchers, and the general public. Monitoring basic water quality ranked among the highest of the Network's vital signs (Route 2004).

A national review panel assembled by the NPS-WRD recommended a suite of five parameters be measured across all NPS monitoring networks (NPS 2002). In addition to these five mandated parameters (temperature, pH, specific conductance, dissolved oxygen, and flow/water level) we added a measure of clarity (secchi depth or transparency depth) to our core suite. The core suite was ranked highest among potential vital signs for aquatic systems of GLKN parks, although it was recognized that these measurements were less diagnostic of water quality degradation than biotic communities and other water quality variables, such as nutrient concentrations.

Inputs of excess nutrients, invasion and spread of exotic species, and contaminants from atmospheric fallout and surface runoff, and how these stressors affect the chemical and biological functions of lakes are key issues of concern. By monitoring an advanced suite of parameters (nitrogen and phosphorus species, dissolved organic carbon, major ions, alkalinity, dissolved silica, and chlorophyll *a*), we will provide data for a thorough understanding of changes in lakes over time.

Our overall goal is to develop a program for monitoring water quality in inland lakes that will contribute to an understanding of the health of ecosystems in park units of the Great Lakes Network. The monitoring protocol is intended to document water quality status and trends for individual lakes and provide an indication of status and trends on a park-wide and network-wide basis. The protocol includes analysis of historical data, sample design, field and laboratory methods, data analysis and reporting, and training and operational requirements.

12.3 Definitions and Abbreviations

APIS…… Apostle Islands National Lakeshore
INDU……..Indiana Dunes National Lakeshore
ISRO……. Isle Royale National Park
PIRO…….. Pictured Rocks National Lakeshore
SLBE……..Sleeping Bear Dunes National Lakeshore
VOYA……Voyageurs National Park
Blanks .....analytical quality control samples analyzed in the same manner as site samples
Equipment blank .....or field blank, sample of distilled, deionized water taken to the field opened and used as sample water would be (i.e., poured through equipment used to handle samples)
Trip blank .....used to indicate potential contamination due to migration of volatile organic chemicals (VOCs) from the air on the site or shipment into the sample vial. Consists of laboratory distilled, deionized water in a 40-mL glass vial sealed with a Teflon septum and is unopened in the field.
Laboratory calibration blank...distilled, deionized water injected directly into an instrument, indicates contamination in instrument or source of water
Laboratory reagent blank.....or method blank, distilled, deionized water manipulated as if it were a sample (digestions, extractions, etc).
CCV .....Continuing Calibration Verification
EPA.....Environmental Protection Agency

EMAP .....Environmental Monitoring and Assessment Program
GLKN .....Great Lakes Inventory and Monitoring Network
m .....meter
MDL.....Method Detection Limit
mg/L.....milligrams per liter
ML.....Method Limit of quantitation
MSDS.....Material Safety Data Sheet
NAWQA .....National Water Quality Assessment Program
NPS .....National Park Service
NPSTORET .....National Park Service Storage and Retrieval Database
QA/QC .....Quality Assurance/Quality Control
QAPP .....Quality Assurance Project Plan
Reference standard.....independently created solution of known concentration
SOP .....Standard Operating Procedure
STORET .....Storage and Retrieval Database
USGS .....United States Geological Survey
µg/L.....micrograms per liter

12.4 Personnel Responsibilities

Personnel will study this SOP prior to beginning work on the project and follow its procedures in order to conduct the project according to outlined QA/QC procedures. This will ensure consistency and comparability when changes in personnel occur.

Field personnel should be adequately experienced and/or trained in using field and water quality sampling equipment. This experience is best obtained through a combination of classroom and hands-on training, including pilot-testing equipment at a nearby water body. Personnel should be familiar with the instruction manuals for all equipment, particularly with regard to calibration and maintenance procedures. See SOP #2, Training and Safety, for more details on training.

The role of the project manager is to serve as a liaison among other related water quality monitoring projects conducted by partners (e.g., state monitoring programs), park staff, other Network staff (field personnel, data manager), a contracted analytical laboratory, and other GLKN monitoring project managers. The individual will coordinate with resource management staff at the parks to ensure parks are informed of monitoring activities. Specific responsibilities of the project manager include the following:

- Coordinate field schedules and availability of supplies with field personnel
- Develop a training program for field personnel
- Develop, document, and oversee the implementation of standard procedures for field data collection and data handling
- Coordinate logistics with park staff
- Develop quality assurance and quality control measures for the project, supervise staff training and conduct quality assurance checks of field sampling techniques at least once, mid-season, with each field crew

- Contract with an analytical laboratory for analysis of water samples, ensure lab results meet program needs (e.g., QA/QC procedures, meaningful minimum detection limits for low level strength waters, adequate reproducibility of replicate samples)
- Supervise or perform data entry, verification, and validation
- Summarize and analyze data, prepare reports
- Serve as the main point of contact concerning data content

The project manager will also work closely with the data manager in the following capacities:

- Complete project documentation in NPSTORET (describing who, what, where, when, why and how of a project)
- Develop data verification and validation measures for quality assurance
- Ensure staff are trained in the use of database software and quality assurance procedures
- Coordinate changes to the field data forms and the user interface for the project database
- Identify sensitive information that requires special consideration prior to distribution
- Manage the archival process to ensure regular archival of project documentation, original field data, databases, reports and summaries, and other products from the project
- Define how project data will be transformed from raw data into meaningful information and create data summary procedures to automate and standardize this process
- Establish meaningful liaisons with state counterparts to promote sharing of data on a timely basis

The field crew leader will be responsible for preparing supplies and equipment for field season; ordering needed supplies; making travel arrangements; maintaining sampling equipment; maintaining field vehicles; ensuring field personnel follow sampling protocols; preparing field data forms, chain of custody forms, and analytical service request forms for each site; notifying contract laboratory of planned sample shipment date; and providing project manager with field trip and check-in schedule.

Field personnel will be responsible for following protocols and standard operating procedures during field activities and the handling of samples.

Roles of staff are explained in more depth in section 5 of the inland lakes protocol narrative, along with training and requirements.

12.5 Sampling Process and Design

The process of developing the sampling for this project included consideration of random versus nonrandom selection of lakes, and the sampling designs of Minnesota, Wisconsin, and Michigan. These three states have the greatest number of lakes of the lower 48 states, have active water quality monitoring programs and contain several of the Network parks. Consistency of the Network's monitoring design and protocol with neighboring state programs is desirable to facilitate data comparisons and allow statistical inferences using regional data. See the Inland Lakes Protocol Narrative for more information on these considerations.

Answering questions about all lakes within a park or all lakes across the network requires either a complete census of lakes or a random selection of lakes, which allows inference to the population of lakes as a whole. A complete census of lakes is not feasible, as the Network contains well over 1,000 lakes. A random selection of lakes is not desirable because many lakes are inaccessible and would require more than a day of off-trail, backcountry travel to reach. We selected lakes, called index lakes, at six park units within the Network to span gradients of chemical and physical parameters, visitor use, watershed size, and spatial distribution within each park. The number of lakes selected at each park unit varies from one to nine (Table 1). We will analyze data separately for individual lakes and address questions at broader spatial extents through comparisons of trends across lakes. (See section 4 of the protocol narrative and SOP #9, Data Analysis, for more details).

Table 1. Number of lakes selected for long-term monitoring of water quality in each GLKN park unit.

Park Unit	Number of Lakes
Apostle Islands National Lakeshore	4
Indiana Dunes National Lakeshore	1
Isle Royale National Park	9
Pictured Rocks National Lakeshore	5
Sleeping Bear Dunes National Lakeshore	6
Voyageurs National Park	8

The information goals and statistical requirements determine the sampling frequency. To identify the long-term trends in a waterbody, the sampling frequency should be sufficient to identify a statistical trend beyond the background variability. Therefore, it is essential to evaluate existing data prior to establishing 1) the number of sites and 2) the frequency of sampling. Statistical power analysis based on the power to detect change guided the selection of these two parameters, using calculations of statistical sample size and analysis of sensitivity to sampling frequency, respectively. The goal is to be able to detect 20% change at 80% power and 5% significance. (See the inland lakes protocol narrative for more details on this power analysis.)

Sampling frequency, therefore, requires a pragmatic compromise among statistical rigor, logistics, and cost. The Network will visit each selected lake three times, annually, during the open water season. Analyses of existing data, such as described in the protocol narrative, help us understand the limitations of our sampling design. We do not expect to be able to detect changes in most variables after only a few sampling years, and realize that it may take many years to detect changes in some highly variable parameters. Given our sampling frequency, we expect even the least variable parameter to require more than 10 years of monitoring data before we will be able to detect a 20% change with 80% power.

12.5.1 Site Selection

The lakes selected for sampling are listed in section 2 of the inland lakes protocol narrative. A single sampling site, typically located in the deepest part of the lake, will be the routine location

for measuring all water quality variables. Sampling the deepest part of the lake allows sampling every possible depth to the bottom, and has a long history in limnology.

The Network will use a 0 – 2 m integrating tube sampler, following the protocol used by Wisconsin and Minnesota and many other states. A near-bottom sample (approximately 1 meter from bottom) will be collected via Van Dorn sampler during mid-summer, when lakes are stratified, for analysis of TP.

12.5.2 Field Collection Parameters

Core field parameters will be measured with a multiprobe (Table 2). Samples will be taken for shipment to a contract laboratory for nutrients (TP, TN, NO_3+NO_2-N, NH_4-N) and chlorophyll-*a* each sampling visit, or three times annually, and the remaining parameters (alkalinity, major ions (Cl, SO_4, Ca, Na, K, and Mg), DOC, and SiO_2) once annually. In addition, a near-bottom sample for TP will be collected once annually from stratified lakes.

Collect water sample(s) with an integrated sampling tube or Van Dorn and process as per SOP #7. In the field log book and on the field data sheet, record information related to the sample collection, including:

1. Lake name and site identification code.
2. Sample date, time, and depth.
3. The amount of water collected.
4. Whether duplicate samples for quality control were collected at this site.
5. Any additional notes or observations pertinent to this sample or location for this sampling period.

Additionally, always keep in mind the following;

- Sample containers should be labeled in indelible ink with, at a minimum, the station name, date and time of collection, and preservation method, if applicable.
- Follow all SOPs for sample collection and preservation.
- To ensure the integrity of the sample, be aware of possible sources of contamination. Contamination introduced during each phase of sample collection and processing is additive and usually is substantially greater than contamination introduced elsewhere in the sample handling and analysis process.
- Use appropriate procedures and quality-assurance measures that ensure sample representativeness and integrity and that meet study criteria. The degree to which a sample can be considered representative of a water body depends on many interrelated factors including temporal and spatial homogeneity of the water body, sample size, and the method and manner of sample collection.

12.5.3 Field Analysis

Dissolved oxygen, temperature, specific conductance, and pH will be measured in the field using a multiprobe and following the methods listed in Table 2. Multiprobes typically perform within the specifications detailed in Table 3. Other parameters may be analyzed at the field station by field personnel in the future.

Table 2. Core suite of field variables and required in situ measurement method.

Field Variable	Method
Temperature (°C)	EPA 170.1
pH	EPA 150.1
Specific conductivity (µS/cm)	EPA 120.1
Dissolved oxygen (mg/L)	EPA 360.1
Clarity (cm)	Transparency tube

Specification of quantification ability for field multiprobes is not a straightforward data quality objective exercise. Most field parameters tend to be those that characterize the waterbody and are not usually based on a criterion limit as would be used for a toxic pollutant. Therefore, instrument selection should be based on the parameters and ranges they can measure, but instrument-specific estimations of the range of uncertainty for each parameter will have to be made when interpreting data. Details on estimating instrument sensitivity are included below in section 12.8.2.

Table 3. Typical sensor performance specifications for multiprobe field instruments.

Sensor	Expected Range	Reporting Resolution*	Estimated Bias	Stabilization Criteria
Temperature	-5 to 45 °C	0.01 °C	±0.15 °C	Thermistor: ± 0.2 °C Glass: ± 0.5 °C
Specific Conductivity (SC25)	0 to 2000 µS/cm	µS/cm (range dependent)	±0.5% of reading + 1 µS/cm	≤100 µS/cm: ± 5% >100 µS/cm: ± 3%
pH	1 to 14 units	0.01 unit	±0.2 units	± 0.1 standard unit
Dissolved Oxygen (Conc.)	0 to 50 mg/L	0.01 mg/L	0 to 20 mg/L: ±0.2 mg/L 20 to 50 mg/L: ±0.6 mg/L	± 0.3 mg/L
Dissolved Oxygen (% sat.)	0-200%	0.1%	~ ±2 %	± 2 %
Depth – Z (pressure sensor)	0 - > 100 m	0.1 m	~ 0.1 m	0.1 m

* Resolution specifications are supplied by the manufacturers of the measuring meters. They are not necessarily closely related to real-world (outdoor) precision or bias, and are sometimes more related to the number of significant figures reported rather than how accurate the extra significant figures are. This is why we will control measurement sensitivity in the actual outdoor measuring environment at least once a year by calculating alternative measurement sensitivity (AMS; see Irwin 2006 for more details on AMS).

12.5.4 Laboratory Analysis

Samples will be collected in the field according to SOP #6 for shipment to a contract laboratory that meets QA/QC requirements outlined in Section 12.8.3 of this SOP. Samples will be analyzed for nutrients (TP, TN, NO_3/NO_2-N, NH_4-N) and total chlorophyll-*a*, each sampling period, while alkalinity, major ions (Cl, SO_4, Ca, Na, K, and Mg), DOC, and SiO_2, which tend to be less variable, will be monitored annually.

Methods chosen will meet quantification limits according to the criteria tabulated below (Table 4). The method limit of quantitation (ML) of the chosen method should be two to ten times lower than the typical expected low value. The ML is the lowest value that can be quantified with certainty. The value in the "ML needed" column of Table 4 is two to ten times lower than the lowest value found in the pilot year of sampling water quality for each analyte. This estimation is used as guide to the selection of the method that will be needed for this project.

The majority of the parameters listed in Table 4 are used in waterbody characterization and do not have criterion lower limits as would a toxic pollutant. Some of the criteria available are listed as maximums not to be exceeded and, as such, do not guide the selection of a method by ML. Guidelines to be used, therefore, include relevant state water quality standards, EPA eco-regional nutrient recommendations (USEPA 2000), state nutrient criteria as they are developed, data results for these parameters from the pilot studies carried out by GLKN, and/or lowest values for the parameter found in relevant Horizon reports (NPS 1995a, 1995b, 1995c, and 1999).

12.6 Sampling Methods

Consistent methods are important to long-term quality data. In actuality, the ideal conditions are not always met in the field or in the lab and changes in staff do occur. Therefore, documentation of procedures, site conditions, laboratory analysis, and reasons for deviations of any kind is important in and of itself for long-term projects. Personnel will be encouraged to write down more than they feel may be necessary in the moment as the future interpretation of their data will depend on the written record and not the memory of an individual.

12.6.1 Site Locations

Refer to description of monitoring station location, directions, and photos to verify correct location. Verify coordinates with a GPS unit. Document this verification. This information will be contained in a site binder along with a table of previous field measurements to compare with new measurements.

A single sampling site, typically located in the deepest part of the lake, will be the routine location for measuring all water quality variables. Sampling the deepest part of the lake allows sampling every possible depth to the bottom, and has a long history in limnology. Except for shallow lakes, this type of sampling ignores the littoral zone and always avoids the nearshore zone, as well as embayments and other features related to morphometry.

Table 4. Analytical detection levels required for GLKN water quality monitoring.

Analyte	Typical Low Value Found	Criteria Source[a, b]	Comment	ML Needed
Alkalinity (mg/L)[c]	ND (<1)	Lowest value pilot yea	MDL unknown	
DOC (mg/L) [c]	3	Lowest value pilot yea	Lab MDL 0.1	0.3 mg/L
Ca^{2+} (mg/L) [c]	2.4	Horizon report	MDL unknown	0.24 mg/L
Cl^- (mg/L) [c]	0.273	Lowest value pilot yea	Lab MDL 0.025	0.02 mg/L
Chl-a (µg/L)	0.63	EPA	Lower of VII and VIII	0.06 mg/L
Cl^- & SO_4^{2-}	230	MN WQS	Lowest of states	1.0 mg/L
Mg^{2+} (mg/L) [c]	0.47	Horizon report	MDL unknown	0.04 mg/L
K^+ (mg/L) [c]	0.24	Lowest value pilot yea	Lab MDL 0.06	0.02 mg/L
Na^+ (mg/L) [c]	0.5	Horizon report	MDL unknown	0.05 mg/L
SO_4^{2-} (mg/L) [c]	0.625	Lowest value pilot yea	Lab MDL 0.025	0.06 mg/L
TP (µg/L)	10	EPA	Lower of VII and VIII	1.0 µg/L
TN (mg/L)	0.38	EPA	Lower of VII and VIII	0.03 mg/L
NH_4-N (ppb) [c]	0.005	Horizon report	MDL unknown	0.001 µ g/L
NO_3+NO_2-N (ppb) [c]	.0002	Horizon report	MDL unknown	0.0001 µ g/L
$Si0_2$ (mg/L)	ND (<0.1)	Lowest value pilot year	Lab MDL 0.2	0.1 mg/L

NOTES:

a: EPA = EPA Ecoregional nutrient criteria recommendations, lower value recommended for aggregate ecoregions VII and VIII (USEPA 2000).

b: WQS = criteria value listed in Ledder (2003) state water quality standards

c: parameter has no official criterion for any of the states, the value reported in the analytical requirement column is the lowest value determined in the pilot year for rivers or lakes or the lowest value found in a spot check of Horizon reports for each park.

12.6.2 Field Water Measurements

Before making field measurements, properly-calibrated sensors (see SOP #6) must be allowed to equilibrate to the condition of the water being monitored. Sensors have equilibrated adequately when instrument readings have stabilized, that is, when the variability among measurements does not exceed an established criterion. The criteria for stabilized field readings were defined operationally by O'Ney (2005) for a set of three or more sequential measurements (Table 5). The natural variability inherent in surface water or ground water at the time of sampling generally can be compared with these stability criteria and indirectly relates to the short term bias or the long term accuracy that should be attainable with a calibrated instrument. Dissolved oxygen typically requires a greater amount of time to stabilize than other parameters. In addition, differences in polarigraphic sensor membrane thicknesses, age, and rates of oxygen consumption increase the variability of the equilibration time. Depending on the site characteristics and the specific oxygen sensor, 3 to 5 minutes may be required for complete equilibration. This time far exceeds what is needed for the other parameters, which typically stabilize in less than 60 seconds. Observers should only note instrument dissolved oxygen readings after the stabilization criteria in Table 5 are met, and then record readings for all parameters at once.

Measure field water quality variables and conduct sampling according to SOP #6, field measurements and water sample collection. Quality results require consistent measurement methods and detection limits.

Depth profiles of temperature, specific conductance, pH, and dissolved oxygen will be measured at each sampling station using a multiparameter instrument (multiprobe). Lake level will be determined at benchmark stations on a regular basis. Details of methods for measuring lake levels are included in SOP #4. Clarity will be measured using a Secchi disk or transparency tube. These core parameters will be measured when water samples for analysis of the advanced parameters are collected.

Begin just below the water's surface (~ 0.3 m depth) and take readings after stabilization of the multiprobe. Lower the sensors to collect a vertical profile of field parameters at 1m intervals until 20 m depth, and then every 2-5 m depending on overall depth and gradients. Replicate 10% of the readings (e.g., at 1 m, 10 m, etc.); take the replicate readings immediately following the original readings. Values should agree within 10% or the acceptance criteria in Table 5, whichever is larger.

At all sites, record visual observation information required on the data sheet. Such observational data can provide important information to the interpretation of field measurements.

If any analyses are to be done in-house, conduct these analyses as soon as possible upon return from the field. A clean analytical station should be prepared in which to work, free of food items, mud, lubricants, or lab chemicals. Hands should be thoroughly washed.

Table 5. Recommended instrument stabilization criteria for recording field measurements[a,b].

Standard Direct Field Measurement	Stabilization Criteria (O'Ney 2005)	Stabilization Criteria *In situ* Multisensors (WOW 2005)
Temperature[c]:		
Thermistor Thermometer	± 0.2 °C	± 0.2 °C (5%)
Liquid-in-glass Thermometer	± 0.5 °C	
Specific Conductivity (SC25)[d]		
When ≤ 100 µS/cm	± 5 %	< 5 µS/cm (10%)
When > 100 µS/cm	± 3 %	
pH[e]: Meter displays to 0.01	± 0.1 unit	± 0.2 unit (10%)
Dissolved oxygen[e]: Amperometric (same as polarigraphic) method	± 0.3 mg/L	± 0.5 mg/L (10%)

Notes:
a: Resolution/sensitivity is a data quality indicator related to detection limits but typically handled differently for field probes than for laboratory parameters. For more information, see Irwin (2004).
b: In the case of field probes, bias is typically a best case maximum deviation from known correct values (typically based on comparisons with known NIST certified reference materials or standards). True accuracy is a combination of high precision and low bias, and is hard to quantify with the small sample sizes used to control bias and precision in typical field measurements (see Irwin 2004 for more details).
c: Recommended sensor calibration is quarterly.
d: Recommended sensor calibration is daily.
e: Recommended sensor calibration is at beginning of sampling day with a calibration check at the end of the day.

12.6.3 Samples for Laboratory Analysis

Prepare bottles and labels prior to field sampling as per SOP# 6. Collect samples using a 0-2 m integrating tube sampler as per SOP #6. For all sampling, it is critical to avoid sampling water showing evidence of oil, gasoline or anything else from the boat. It is best to kill the engine and set the anchor, if possible, although this may not be possible or advisable in bad weather or with a balky engine.

Prior to filling sample bottles sent by the laboratory, first rinse the bottle once with sample water, if the bottle is not pre-preserved. Some analyses require preservation of the sample with acid, which may be added to the bottle by the contract laboratory; in these cases do not rinse the bottle first. Take care not to overfill the bottle if the bottle is pre-acidified, as overfilling will flood the acid out of the bottle. If the samples requiring acid preservation are not pre-preserved, use caution to add the ampule of preservative supplied by the lab and immediately rinse hands in water if acid is spilled. Protective gloves are recommended.

Table 6 summarizes the variety of methods, detection limits, preservation techniques, and holding times for water samples addressed by this protocol. These methods conform to those

used by Minnesota, Wisconsin, and Michigan for state certification of environmental laboratories involved in Clean Water Act or drinking water sample analysis (MDH 2005, WSLH 2003, MDEQ 2005). They are also used by EPA-funded research projects of natural waters in the upper midwestern U.S. Holding times shall in no case be less stringent than those recommended by EPA in 40 CFR Part 136 to 136.3 and appendices. Refer to SOP #6 for additional details regarding sample collection and preservation.

Samples are stored in a cooler with ice packs during field sampling. Prepare samples for shipment according to the contract laboratory's protocols. These protocols will be provided to the field sampling personnel for each sampling round so that the proper procedures are accessible in the event of contract laboratory changes. In general, samples are shipped on ice to maintain a temperature of approximately 4 $^{\circ}$C. A plastic bag is placed in the cooler first. Sample bottles are packed among zip lock bags of ice and/or ice packs to prevent water leakage into the sample bottle during shipment. Prepare a temperature check bottle for each anticipated cooler, if recommended by the contract analytical laboratory. Use tap water to fill an extra bottle of the same size used for one of the analytes and label as "Temperature Check". Store this check bottle in refrigerator with other samples; package and send to the analytical laboratory with the other samples. Some analyses require the sample to be frozen for shipment; such frozen samples are likewise packed among ice packs for shipment to the contract laboratory.

Follow the shipping company's requirements in preparation of the cooler of samples for shipment. Packaging problems may cause delays in shipment, which can mean that samples do not arrive at the laboratory at the proper temperature or past holding time, compromising data quality. In general, the ice and samples should be contained within a sealed plastic bag within the cooler so that the cooler does not leak. Packing tape should be wrapped around the cooler vertically and around the lid seam horizontally to ensure it remains closed. A note on the cooler that it contains water samples is helpful as well so that if leakage occurs, carriers will know the contents are not hazardous.

12.6.4 Sampling Forms

Before leaving the monitoring site, all field forms and sample labels must be reviewed for legibility, accuracy, and completeness. Any changes in procedure due to field condition must be explained in the comments section. Make sure the information is complete on all forms. Record the departure time on the field form. After reviewing each form, initial the upper right corner of each page of the form. Document any photos taken by including the photo number and roll number or digital camera photo number on the field form.

Table 6. Example range of analytical methods, method detection limits (MDLs), containers, and holding times.

Analyte	Analytical *Note 1*	Method #	Det. Limit	Vol. (ml)	Filter	Preservation	Sample Bottle *Note 2*	Hold Time
Alkalinity	Titrimetry	310.1 EPA-NERL	10 mg/L			4°C		14 days
	Spec. auto.	310.2 EPA-NERL	10 mg/L			4°C		14 days
	Titrimetry	NFM USGS-OWQ	0.01 meg/L		*Note 4*	None		none
Calcium	ICP	3120B APHA	10 ug/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
	Titrimetry	215.2 EPA-NERL	0.5 mg/L		*Note 3*	4°C		6 mos
	FAA	I-3152 USGS-NWQL	0.1 mg/L	250 mL	*Note 3*	pH<2 HNO_3	P	180 day
Chloride	IC	300.0 EPA-NERL	0.02 mg/L			4°C	P or G	28 day
	Colorimetry	325.2 EPA-NERL	1 mg/L			4°C		28 day
	Titrimetry	4500-Cl APHA	0.15 mg/L	100 mL		4°C	P or G	28 day
Chlorophyll-a	Spect.	10200 APHA	2 ug/L	≤ 1 L	*Note 4*	Freeze filter	P	30day
Color	Spect.	110.2 EPA-NERL	5 Pt units		*Note 5*	4°C	G	48 hours
	Vis. Comp.	I-1250 USGS-NWQL	1 Pt-co	250 mL	*Note 5*	4°C	P	30 days
DOC	Spect.	415.3 EPA	0.018 mg/L	125	*Note 3*	pH<4 H_2SO_4	G	28 days
	Spect.	0-1122-92 USGS	0.1 mg/L			4°C	AG	
K	ICP	3120B APHA	0.3 mg/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
	FAA	3111B APHA	5 ug/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
Mg	ICP	3120B APHA	20 ug/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
	FAA	3111B APHA	0.5 ug/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
Na	ICP	3120B APHA	30 ug/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
	FAA	3111B APHA	2 ug/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
NH_4-N	Selective elec.	4500-NH_3E	0.08 mg/L			4°C/pH2,0°C		24h/28d
	Colorimetry	350.2 EPA-NERL	0.08 mg/L			pH<4 H_2SO_4		28 day
	Titrimetry	4500-NH_3 APHA	5 mg/L			4°C/pH2,0°C		24h/28d
SiO_2	ICP	3120B APHA	20 ug/L		*Note 3*	pH<2 HNO_3	P or G	6 mos
	Spect.	4500- SiO_2 D APHA	0.04 mg/L		*Note 3*	No, 4°C	P	28 days
	FIA-Spect.	4500- SiO_2 F APHA	0.78 ug/L		*Note 3*	No, 4°C	P	28 days
TSS	Gravimetric	I-3765 USGS-NWQL	1 mg/L	250-500	*Note 4*	4°C filter	P	NA
SO_4	IC	4110C APHA	75 ug/L		*Note 3*	pH<4 H_2SO_4	P or G	
	CIE-UV	D6508 ASTM	0.1 mg/L		*Note 3*	pH<4 H_2SO_4		ASAP
	Spect.	37512 EPA-NERL	0.5 mg/L		*Note 3*	pH<4 H_2SO_4	P or G	28 days
TP	Spect.	I-2606 USGS-NWQL	0.001 mg/L	125 mL		MgCl 4°C	BrownP	30 days
	Alkaline P	USGS 2003	0.01 mg/L	120 ml	*Note 6*	4°C /H_2SO_4		48 h/30d
	ICP	200.7 EPA-NERL	60 ug/L			pH<2 HNO_3	P	6 mos
TN	Alkaline P	USGS 2003	0.03 mg/L	120 ml	*Note 6*	4°C /H_2SO_4		48 h/30d
	Titrimetry	4500-N	0-100 mg/L			4°C	AG	7 days
	Combustion	440.0 EPA-NERL	0.1 mg/L			Filter		100 day

Source: National Environmental Methods Inventory website (NEMI 2006)

This list is not an endorsement of any particular method or laboratory for any particular analyte. Rather it is to be used as a reference for the range of analytical methods available for each analyte. There are surface water conditions (pH, turbidity, other elements) that make a particular method unsuitable for a particular situation. As GLKN is monitoring surface water, the methods listed were chosen as representative of the lower range of detection limits.

Note 1. CIE-UV= capillary ion electrophoresis with UV detection, FAA = flame atomic absorption, FIA = flow injection analysis, IC= ion chromatography, ICP = inductively coupled plasma, Spec. auto = spectroscopy with autoanalyzer

Note 2. P = plastic (polypropylene), G=glass, AG=amber glass

Note 3. 0.45µm membrane filter. Pre-filter for dissolved portion analysis.

Note 4. 0.45µm glass fiber filter.

Note 5. 0.45µm membrane filter or centrifuge is recommended to remove suspended solids that affect color, however some color will also be removed.

Note 6. USGS 2003. Evaluation of Alkaline Persulfate Digestion as an Alternative to Kjeldahl Digestion for Determination of Total and Dissolved Nitrogen and Phosphorus in Water By Charles J. Patton and Jennifer R. Kryskalla. U.S. Geological Survey Water-Resources Investigations Report 03-4174.

12.7 Handling and Custody

One part of proper data and sample handling procedures is to provide a complete record of the methods and procedures followed. Complete records are important to long-term monitoring so that anyone using the data may trace the sampling history.

12.7.1 Field Data

Field data will be collected on forms printed on waterproof paper. While at each monitoring site, the information recorded on the forms should include:

- Date and day of week
- Time of arrival
- Names of field team members
- GPS coordinates, to verify location
- Current weather (air temperature and wind speed) and relevant notes about recent weather (storms or drought)
- Observations of water quality conditions
- Description of any photographs taken
- Multiparameter sonde (model), calibration date, and field measurements of core suite variables
- Sample identification numbers and collection times for advanced suite variables or quality assurance samples
- Samples taken for laboratory analysis
- Whether any samples were not collected, and reason
- Water level
- Any other required metadata for NPSTORET data entry
- Time of departure

All entries should be made clearly. If an incorrect entry is made, a single heavy line should be drawn through the incorrect entry and the correction made. All corrections should be initialed and dated. The completed field forms will be maintained in chronological order by station, copied into site binders and the originals maintained on file indefinitely. Field data are reviewed annually by network personnel (see SOP #8, Data Entry and Management, for details).

12.7.2 Site/Sample Identity Codes

Sampling stations will be identified by park and water body according to Network guidance. Information on the sampling station and park will comply with NPSTORET requirements.

12.7.3 Data Transfer

Enter field and laboratory data into NPSTORET as soon as possible after receiving the data, according to SOP #8. Field forms are the only written records of field measurements; place copies in office binders and keep originals on file indefinitely. Program sampling data and

associated records are archived and stored in the GLKN Ashland Office. Boxes are numbered consecutively by year, project, and station number.

Personnel entering data into the database should take care to enter laboratory data in consistent units. Different laboratories may report analytical results in different units (mg/L vs. µg/L) for the same analyte. Follow SOP #8, Data Entry and Management, when entering data.

The contract laboratory should use the STORET-supported laboratory remark codes (Table 7) or provide a map relating their remark codes to these. Unlisted remark codes should be discussed for possible addition by the USEPA to the STORET codes. The detection descriptors to be used in data entry to STORET are listed in Table 8.

Table 7. STORET-supported laboratory remark codes.

AL	Aldol condensation present. Analyte may not be present.
CNT	Non-acceptable colony counts.
EHT	Sample or extract held beyond acceptable holding time.
FBK	Analyte found in blank. Sample contamination indicated.
FDB	Failed. Dry blank not acceptable.
FDC	Failed. Drift check not acceptable.
FIS	Failed. Internal standard not acceptable.
FLD	Failed. Lab duplicate not acceptable.
FFD	Failed. Field duplicate not acceptable.
FFB	Failed. Field blank not acceptable.
FFS	Failed. Field spike not acceptable.
FFT	Failed. Trip blank not acceptable.
FLC	Failed. Linearity check did not meet quality criterion.
FLS	Failed. Lab spike recovery not acceptable.
FMS	Failed. Matrix spike recovery not acceptable.
FPC	Failed. Lab performance check not acceptable.
FQC	Failed. Quality control criteria exceeded during analysis.
FRS	Failed. Internal reference sample not acceptable.
FSP	Failed. Surrogate spike recovery not acceptable.
FSB	Failed. Spiked field blank recovery not acceptable.
FSL	Failed. Spiked lab blank recovery not acceptable.
INT	Interference suspected. Analyte may not be present.
ISP	Improper sample preservation noted. Analysis performed.
LIS	Lab internal standard(s) added to sample.
LLS	Value less than lower quality control standard.
PRE	Presumptive evidence that analyte is present.
NJ	TIC, Tentatively Identified Compound, result is approximate
N	TIC, Tentatively Identified Compound, presumptive id only
OUT	Result value is defined as an outlier by data owner
SUS	Result value is defined as suspect by data owner

Table 8. STORET detection descriptors.

Detected and Quantified
*Non-detect
*Present >QL
*Present <QL
*Not Reported
*Present

12.7.4 Sample Transfer

Conduct sample processing per SOP #7. Refrigerate or freeze samples, as required. Conduct in-house laboratory work and package samples for sending to contract analytical laboratory. Sample preservation and conditions for shipment will differ for each parameter; these needs should be discussed ahead of time with the contract laboratory and documented. Fill out the analytical request form and chain-of-custody (COC) form provided by the laboratory (examples are included in SOP #7). The COC form is used to document the taking, shipment, and receipt of samples. The laboratory will use the COC to check samples into the analytical process. Clean all transfer bottles and equipment according to SOP #7. Water samples are maintained as close to sampling conditions as possible by shipping on ice. Chain-of-custody documentation will be maintained. A chain-of-custody includes not only the form, but all references to the sample in any form, document, or log book that allow tracing the sample back to its collection, and documents the possession of the samples from the time they were collected until the sample analytical results are received.

12.8 Analytical Methods

Field equipment and contract laboratories are likely to change during the course of this long-term monitoring project. Documentation will be maintained, therefore, as regards each multiprobe and contract laboratory's ability to meet the data quality objectives of this project. Forms for this purpose are included in Attachment A. These completed forms for each multiprobe and contract laboratory will be maintained along with the maintenance logs for the multiprobe and QAPPs for each analytical laboratory.

12.8.1 Field Methods

One important aspect in the low uncertainty/bias and high precision of a water quality monitoring program is the correct selection probes for measuring field variable and their subsequent calibration and maintenance. Table 3 lists typical field sensor performance specifications that should be expected from monitoring equipment for this protocol. Table 9 summarizes the ideal calibration frequency and minimum acceptance criteria for these sensor probes. The reality of logistical constraints at back country sites may preclude calibration and checks of calibration at the ideal frequency.

Table 9. Ideal calibration frequencies and acceptance criteria for field instruments.

Parameter	USEPA Method	Minimum Calibration Frequency and QC checks	Acceptance Criteria	Corrective Actions
Temperature thermometer:	170.1	Annually, 2-point check with NIST thermometer	±1.0 ºC	Re-test with a different thermometer; repeat measurement
Temperature thermistor:	170.1	Annually, 2-point check with NIST thermometer	±1.0 ºC	Re-test with a different thermometer; repeat measurement
Specific Conductance (SC25)	120.1	Daily, prior to field mobilization; calibration check prior to each round of sampling; 10% of the readings taken each day must be duplicated or a minimum of 1 reading if fewer than 10 samples are read.	±5% RPD 10%	Re-test; check low battery indicator; use a different meter; use different standards; repeat measurement
pH	150.1	Daily, prior to field mobilization (two buffers should be selected that bracket the anticipated pH of the water body to be sampled with an independent third buffer selected to check instrument performance in that range); Calibration check w/ third buffer prior to each round of sampling 10% of the readings taken each day must be duplicated or a minimum of 1 reading if fewer than 10 samples are read.	±0.05 pH unit ±0.1 pH unit RPD 10%	Re-test; check low battery indicator; use different standards; repeat measurement; don't move cords or cause friction/static
Dissolved Oxygen	360.1	Daily, prior to field mobilization; check at the field site if elevation or barometric pressure changed since calibration	0.2 mg/L concentration or ±10% saturation	Re-enter altitude; re-test; check low battery indicator; check membrane for wrinkles, tears or air bubbles; replace membrane; use a different meter; repeat measurement; allow more time for stabilization
Depth	--	Daily, prior to field mobilization, check at the field site. Check annually against commercially purchased brass sash chain labeled every 0.5 m to ensure that it reads zero at the surface and varies <0.3 m for depths <10 m and no more than 2% for greater depths.	±0.1 m	Retest, check low battery indicator; repeat measurement; use with accurately calibrated line
Transparency tube	--	Transparency tubes have a 100 or 120 cm scale; ensure tube is clean	±1.0 cm for transparency tube	
Marked lines (e.g., Secchi, Van Dorn)	--	Check markings annually against brass sash chain. If lines are heated (for decontamination) check prior to each round of sampling.	±1%, 0–10 m ±2%, >10 m	Re-mark line.

Ensure calibration standards are not used beyond expiration dates. Refer to SOP #6 for an explanation of each parameter measured, guidelines on potential field measurement problems,

and other details on performing calibration checks. Keep the manufacturer's manual with each instrument for aid in troubleshooting.

Used calibration solutions, in general, may be rinsed down a sink with water after consideration of the wastewater treatment system available to that sink. Material safety data sheets (MSDS) which are sent with manufacturer purchased calibration solutions should be kept on file. These documents describe the flammability, toxicity, and other safety hazards of reagents. Some reagents may include constituents toxic to aquatic life. These should not be rinsed down a sink in any large quantities in primitive areas where the ultimate destination of wastewater is the aquatic environment. These reagents should be collected in a leak-proof container that is properly marked, and disposed of in an adequate treatment system.

Calibration logs for multi-parameter sondes will be maintained and will document the frequency of calibration and calibration checks. Data reporting units will be standardized by using the data sheet. Keep calibration and maintenance logs for multiparameter sondes with the sonde during the sampling season. Logs will later be archived at the Network office in Ashland, Wisconsin. A new log will be started for each field season.

12.8.2 Field Equipment Performance Criteria

Estimates of the completeness, representativeness, precision, comparability, and systematic error of data generated by the use of a multiprobe will be estimated and documented according to this SOP.

Data will be considered representative of the lake when procedures detailed in the inland lakes protocol narrative and associated SOPs are followed. Actual sampling location and changes due to field conditions will be documented on the field forms. Data will be comparable year-to-year as objectives and methods chosen are consistent within documented NPS GLKN sampling procedures.

12.8.2.1 Field Data Completeness

The completeness of data collected, or percentage of intended field measurements that were actually made, will be calculated at year's end according to the formula below.

$$Percent_completeness = \left(\frac{\#samples_collected}{\#samples_planned} \right) \times 100 \quad (1)$$

12.8.2.2 Instrument Sensitivity

Sensitivity of the multiprobe will be documented through an estimation of the limits of detection known as alternative measurement sensitivity (AMS). The AMS for each multiprobe will be estimated annually, and for any new multiprobes, by taking multiple (at least 7) measurements in a field simulation for each parameter. Alternative Measurement Sensitivity (AMS) is a two-sided estimation based on the 99% confidence interval for sample size 7. Of interest is the size of the difference between two individual values that can be considered to actually be a true difference. This calculation differs from the MDL, which is a one-sided true difference from zero. The standard deviation will then be calculated and used in the estimation of AMS (3.708 x SD). This

estimation will be carried out and documentation kept for a new probe and annually thereafter. A checklist (Attachment A) will be used for this documentation. Documentation will be kept in the project files.

12.8.2.3 Instrument Precision

The precision of the multiprobe will be estimated through the use of duplicates. Duplicates will be measured each day in the field at a rate of 10% (or 1 per park sampled if fewer than 10 sites are sampled). A reading will be considered a duplicate when it is repeated at a particular sampling site immediately after it is initially taken. Only the surface reading need be replicated. This will reduce the contribution of variability from the variability of the lake itself. Precision calculations are made by way of a Relative Percent Difference (RPD). Measurement Quality Objective (MQO) for precision: The RPD should be less than or equal to 10%; details and corrective actions are listed in Table 10. Calculate precision as follows;

$$Precision = \left(\frac{A - B}{(A + B)/2} \right) \times 100 \quad (2)$$

where A is the first reading and B is the second reading taken immediately after the first.

Table 10. Frequency, acceptable range, and corrective actions for quality control (QC) samples.

Type of QC Sample	Frequency	Acceptable Range for MQOs	Corrective Action
Field Duplicates (samples)	Minimum of 1 per trip per parameter or 10% of all samples per parameter per day	All parameters ±15% RPD, chlorophyll-a, TSS and nutrients ± 30%	Audit field personnel and verify sample collection procedure; resample; reanalyze; revise SOP; audit and train field personnel; project manager determines whether associated data is usable
Field Duplicates (multi-probes)	Minimum of 1 per trip per parameter or 10% of all samples per parameter per day	All parameters ±10% RPD	Re-calibrate instrument; replace batteries; perform instrument field check with different standards; repair or replace instrument; notify management; audit and train field personnel; project manager determines whether
Laboratory Control QC (bias)	One each per analytical batch, minimum 1 per 20 samples	All parameters ± 15% RPD	According to laboratory QAPP, ensure re-calibration, re-analysis and documentation.

12.8.2.4 Instrument Bias

The systematic error/bias of the multiprobe will be estimated through the use of reference solutions. Reference solutions will be measured prior to each round of sampling, in the lab or field. The results will be documented and used as a calibration check according to Table 9 as

well as for a long-term estimate of systematic error/bias. Bias calculations are made by way of a Percent Difference (PD). Calculate bias as follows:

$$Bias = \left(\frac{Y - X}{X} \right) \times 100 \quad (3)$$

where X is the known (or expected) amount, and Y is the measured concentration.

12.8.3 Laboratory

The ability to use environmental data to reveal long-term trends requires consistent analytical methods and detection limits. The NPS recommendation is to use only laboratories with NELAC certification or at least certification by the state programs that also use the laboratory. The chosen contract laboratories must prove their capability annually through participation in blind quality control checks and other methods prescribed by the states in which they receive certification and/or federal programs in which they participate. Copies of certifications for each analyte and/or method will be kept on file along with Quality Assurance Project Plans (QAPPs) for each laboratory contracted for the duration of this monitoring effort.

The method used in calculating method detection limits (MDLs) and method limit of quantitation (ML) or laboratory reporting limits (Lt-RL for USGS labs) may differ for each contract laboratory. Most laboratories routinely recalculate MDLs, MLs, and QC sample control limits using repeated measurement of standard samples or multiple percent recoveries on a quarterly or annual basis. The GLKN will request and maintain copies of this information as most recently calculated for the relevant analytical methods to assist in the selection of contract laboratories, data validation, and AMS calculations.

A checklist to be used in selecting contract laboratories and documenting their compliance with GLKN QA/QC expectations is included in Attachment B.

Great Lakes Network staff validating laboratory data for database entry should take care to ensure that data are entered in consistent units, as different laboratories may report results in different units (mg/L or µg/L) for the same analytes. A checklist to be used in data validation is included in Attachment B.

12.8.4 Laboratory Performance Criteria

Comparability, representativeness, precision, systematic error, and completeness of data generated by contract laboratories will be estimated and documented according to this SOP during data validation. Table 10 can be used as a guide. Unless otherwise justified (for example, to be consistent with State requirements), in no case will Measurement Quality Objectives less stringent than the following be accepted:

- Precision - A maximum of 10% RPD for all lab parameters except chlorophyll-*a* and nutrients, for which the maximum RPD is 30%

- Bias – A maximum of 15% PD for all parameters, or State credible data defaults, whichever is more stringent.

All MQOs will be used as data rejection criteria.

The data delivery package must contain QC sample results and an explanation of new STORET and NPSTORET compatible laboratory flags. A checklist to be used for documenting this procedure is included in Attachment B.

Data generated will be considered representative of the particular site when samples are taken according to the sampling protocol for each sampling objective. Actual sampling location and changes due to field conditions will be documented on the field forms. Data will be comparable year-to-year as objectives and methods chosen are consistent within documented sampling procedures.

12.8.4.1 Laboratory Data Completeness

The completeness of data analyzed, or the percentage of intended sample measurements that were actually made, will be calculated at year's end according to the formula below. Data points may be missed due to site conditions, sample container breakage, or disqualified analyses due to control limit exceedances in the laboratory. The reasons for missing data should be documented.

$$Percent_completeness = \left(\frac{\#samples_analyzed}{\#samples_planned} \right) \times 100 \quad (4)$$

Determining required sample sizes and attendant completeness goals was done in a stepwise manner, considering desired statistical power and minimum detectable differences (see discussions in the protocol narrative). Should percent completeness ever fall below sample sizes needed for MDD and analysis of trends, adaptive changes will be made to ensure it does not happen again.

12.8.4.2 Laboratory Sensitivity

Measurement sensitivity is estimated in laboratory analysis through the use of signal to noise ratios or the standard deviation of repeat measurements of a low level reference standard. The method each laboratory uses to calculate MDLs and MLs will be documented using the data validation check list. This information will be reviewed during data validation and kept along with other QA/QC information for each laboratory.

12.8.4.3 Laboratory Precision

Measurement precision and bias are estimated using a number of QC samples during a round of sample analysis for each method. A reference standard of a certified known concentration is analyzed along with samples at a rate specified by the laboratory's QA/QC program. The results of these samples are reported and the percent difference calculated. Laboratory duplicates of field samples are also analyzed. This is a field sample that is split or subject to repeat analysis within the laboratory to estimate and control precision repeatability. Relative percent differences are calculated for laboratory duplicates. The percent difference and RPD of these QC samples

should fall within the control limits specified by the laboratory (usually 10% to 20% depending on the type of analysis made).

Field duplicates are to be sent to the analytical laboratory at a rate of at least one in every 10 samples. A field duplicate is a split sample, or at minimum, a sample co-located in time and space. The duplicate is usually given a separate sample identity on the sample label and forms, and it is noted on the field form for which sample this is a duplicate. This is a separate check on precision and repeatability of the laboratory analysis. The precision measurement is calculated using the Relative Percent Difference (RPD) between duplicate sample results per analyte. Precision estimates should be performed within seven days of receipt of laboratory results as part of data validation. Acceptance criteria and corrective actions are summarized in Table 10.

12.8.4.4 Laboratory Bias

Systematic error/bias (formerly referred to as percent recovery) is estimated for each laboratory method through the analysis of spiked samples and/or certified reference materials. Spiked sample analyses are conducted by the contract laboratory to ensure the reported data are accurate, or compare favorably to the true values. A spiked sample consists of a sample with a known concentration of analyte added before any sample preparation procedures are carried out. Sample and spiked sample are analyzed using normal procedures and the percent spike difference is calculated. Percent difference is calculated as bias (equation 3, above).

Other sources of systematic error in monitoring programs include sample cross contamination from field sampling equipment used to handle a multiple number of samples. Equipment blanks are used to estimate whether systematic error is added to sample data during sample handling. The integrated sampler is to be rinsed in the field three times at each site prior to taking samples. Compositing jugs that are not site-dedicated may also be a source of cross contamination. Collect an equipment blank periodically, as follows:

1. In between sample sites, rinse the equipment used to transfer water samples (integrating sampler or compositing jug) with laboratory reagent grade water three times and discard.
2. Rinse with a fourth aliquot and save this aliquot to lab bottles as if it were a lake sample to be analyzed.

This sample is labeled equipment blank and information kept on a datasheet describing the source of the blank. Results for all parameters should be non-detect. This type of blank is a check for cross contamination between sampling sites and control for bias introduced by cross contamination.

The laboratory QAPP should define control limits to be used during analysis of samples. If the analysis QC samples are not meeting the control limits, the analysis is usually repeated after re-calibration. This protocol should be documented in the lab's QAPP. During data validation GLKN will ensure that the laboratory performance meets the precision and bias MQOs tabulated in Table 10.

12.8.5 Changing Methods and Documenting Cumulative Bias

When a field method is changed, the cumulative bias, or change in sampling results due to the method change alone, should be estimated. Cumulative bias can become significant over time

even though changes in methods are small. When change occurs due to a scheduled change in staff, both the new staff member and old staff member should perform side-by-side field measurements several times (minimum of seven) during training when possible. The results for both will be compared as below.

When purchasing a new probe, it should be used for a minimum of seven measurements side-by-side with the existing probe when possible.

When a change in laboratory methods is made by the laboratory, the laboratory will be responsible for estimating any bias introduced by the change. When a laboratory contract is changed to a different laboratory, a minimum of seven samples will be split for analysis in both labs. Data from these comparisons will be used to calculate a percent difference (PD) and fraction of change:

$$PD = \left(\frac{new - old}{old} \right) \times 100 \quad (5)$$

$$Fraction_of_change = \left(\frac{old}{new} \right) \quad (6)$$

where *old* = data from the older or original method and *new* = data from the new or replacement method. Ideally, the average PD (two-sided 95% t-distribution confidence interval) will be within 20% of the mean of the old or the new method measurements. If this is not the case, the number of overlapping measures should be increased until this criterion is met (Irwin 2006). New values can then be normalized to the old method value by multiplying them by the fraction of change.

Any bias should be stated clearly and documented. Documentation will be stored within each site file and should also include:

- all raw data pairs for future use
- standard deviation
- the MDL or AMS of the method
- number of paired samples
- 95% t-distribution confidence interval for the measurement difference
- dates between which overlapping measurements were made
- date documentation calculation was made

These comparison of methods will be carried out, when possible, in order to document any bias that is introduced into the long-term data by a change in methodology and not in the actual environment. Due to the logistical realities imposed by sampling in remote locations and the reality of equipment loss or damage and abrupt changes in staff, this type of comparison may not always be possible.

12.9 Instrument Calibration Frequency, Inspection, and Maintenance

Instruments used in field measurement or laboratory analysis often require frequent inspection and maintenance to ensure they are in good working order. Calibration frequencies differ by instrument and should be spelled out in SOPs for both field and laboratory work to ensure consistency.

12.9.1 Field Instruments

Each instrument must have a logbook. The calibration schedule must be observed, using fresh calibration standards. Calibration solutions may be disposed of by rinsing down the work space sink if the contents do not include constituents which would harm the pipes or aquatic life on the receiving end of the available wastewater treatment (see relevant MSDS sheets). Calibration checks must be documented.

When sensor probes are to be stored for extended periods of time, thoroughly clean sensors, remove batteries, and store sonde according to specific instructions in SOP #11 and manufacturer's manual. Store calibration standards and electrolyte solutions in a temperature-controlled environment.

12.9.2 Laboratory Instruments

Instrument calibration and verification is performed at least once a day for each analytical method prior to the analysis of samples. Each laboratory specifies its own procedure, which should include multiple point calibrations plus a blank, continuing calibration verification, and final calibration verification at the end of an analytical run. Each laboratory should define the procedures in a QAPP. Review of these procedures will be documented using the laboratory checklist in Attachment B.

12.10 Inspection and Acceptance of Supplies and Consumables

Monitoring water quality requires many pieces of equipment and a large amount of supplies. Table 11 lists the SOPs that include checklists of supplies and equipment. When new equipment is received or equipment is returned after repair, inspect it for flaws and test it to ensure proper functioning. When supplies are received, inspect them to ensure containers are properly sealed. Ensure reagent containers are dated upon receipt and upon opening. Commercially purchased calibration standards come with an expiration date that must be observed.

Table 11. Checklists of equipment and supplies for monitoring water quality of inland lakes.

Checklist	Location
Safety equipment and supplies	SOP #2
Decontamination equipment and supplies	SOP #5
Field equipment and supplies	SOP #6
Laboratory equipment and supplies	SOP #7

12.11 Records Management

All records must be kept, from field activity through sample results. Required metadata will be complete. Table 12 summarizes the QA/QC procedures related to data management. For more details on the Great Lakes Network's overall strategy for metadata generation, management, and distribution see chapter 8, Data Documentation, of GLKN's Data Management Plan (Hart and Gafvert 2005) and the appendices of that document.

Data will be archived according to SOP #8 (Data Entry and Management) for digital data, paper copies, and field forms. Field forms are maintained indefinitely. Brief characterizations of the data from each NPS unit that was sampled and the Network as a whole will be performed each year, after all QA/QC procedures have been completed. For each station sampled, these descriptive statistics will include mean, median, maximum and minimum values, skew, kurtosis, and measures of variability (e.g., CV, standard error, variance) for each water quality variable. Understanding of landscape-scale dynamics will be provided by analyses of variability among stations within the domain of interest (e.g., park unit), following one of several approaches described in SOP #9, Data Analysis.

A 'Memo-to-file' will be used to document any decisions or corrections that are made. This memo will include the date, name of author, site or sample referred to, a description of the problem or error and a statement describing the decision made or action taken. The memo will be archived with the appropriate site data and files.

12.12 Assessment and Oversight

It is the project manager's responsibility to make sure each component of this and other SOPs are followed.

12.12.1 Corrective Responsive Actions

The project manager, in consultation with experienced professionals, will be responsible for taking corrective responsive action in the case in which QA/QC is not followed or in the case of an unexpected event. Responsive action is often needed in the event of broken sample bottles, missing data, errors on field sheets, changes due to field conditions, problematic analyses, and other events that do not fall within the standard operating procedures. A "Memo-to-file" will be used to document any decisions or corrections that are made. This memo will include the date, name of author, site or sample referred to, a description of the problem or error and a statement

describing the decision made or action taken. The memo will be archived with the appropriate site data and files.

Table 12. Summary of QA/QC procedures pertaining to data management.

Procedure	Description
Instrument calibration logs	Each instrument must have a logbook.
Field forms	Field forms are the only written record of field measurements. Place copies in site binders and keep originals on file indefinitely.
Estimating precision	The precision measurement is calculated using the Relative Percent Difference (RPD) between duplicate sample results per analyte. Precision estimates should be performed within 7 days of receipt of laboratory results.
Electronic data entry	Approximately 10% of electronic data entries should be spot checked for errors on a random basis. If errors are found, another 10% are spot checked.
Data archiving	Sampling data and associated records are archived in boxes and stored at the GLKN Ashland office. Boxes are numbered consecutively by year, project, and station number.
Data validation	Data validation is the process that determines whether quality control objectives for data collection were met.
Data validation reports	Data validation reports provide a narrative that discusses any deviations from QA/QC procedures and the impacts of those deviations.
Data verification	Data verification demonstrates that a data set will qualify as credible data.
Data verification reports	Data verification reports document the results of the data verification procedure.
Data qualification codes	Data must be fully qualified before uploading to the Water Resources Division's NPSTORET

12.13 Reports to Management

Routine data summaries will occur annually for lakes sampled within that year, and annual summary reports will be produced, with the primary audience being the parks. These reports will be provided to parks and partners as soon as possible following the sampling season.

More comprehensive analyses of trends will occur for most parameters after three or more years of sampling. For stations that are located where no previous monitoring has occurred, this period of time tends to be the minimum needed to establish a time series sufficiently powerful to detect meaningful levels of change (e.g., 20%) through time. The target audience of the analysis and synthesis reports will be the parks, the Network, both regional and Servicewide I&M, and the broader scientific community. Drafts will be reviewed internally and sent to the parks, and possibly outside sources, for further review. The extent of review will depend on how analytically complicated the methods are and the gravity of inference and recommendations.

12.14 Data Validation and Usability

Data validation is the method in which data are proven or disproved to be accurate. This process involves the review of the results of all measurements, samples, and QC samples. Field data sheets and laboratory data are reviewed for transcription errors, completeness, verification of calibration and quality control check samples or standards.

A checklist for use in data validation is presented in Attachment B. Data are validated by comparing the actual estimates for MDL and ML, precision, bias/uncertainty for each analytical run to the expected quality of results. Once this information is documented, the decision is made by the project manager on the usability of the data. Data may be flagged as between MDL and ML and therefore highly uncertain (J). Data may be flagged (B) if the analyte was detected in the blank at a concentration similar to that in the sample (laboratory flagging rules may differ slightly). These types of flagged data contain much more uncertainty than unflagged data. The decision must be made whether or not to add them to the database or merely maintain them in files for future reference. Some investigation into the sampling method or laboratory method may be needed if 'B' flagged data are a continual occurrence or if the required MLs are repeatedly unmet.

NPSTORET itself includes some form-based QA/QC tests on data entry. The system does not allow entry of results below the ML but will flag the data as "present, not quantified". The project manager, in consultation with other NPS or outside experts, will flag data when they fall outside of expected limits. Laboratory results below detection limits (ND) will be kept in the archives as 'ND' and will be handled statistically according to recent literature (e.g., Helsel 2005) in summary and analysis reports.

12.15 Reconciliation with Data Quality Objectives

Once data validation is complete, the project manager then calculates percent completeness, compares the results to the data quality objectives, and determines whether or not the data meet the objectives for both the field and laboratory components of the project.

12.16 Literature Cited

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Attachment A

Check Lists for:

- Analytical Methods
- Selection of Multiprobe
- Selection of Laboratory

Multiprobe Checklist

Probe _____ Purchased _____
Serial Number_____ Location used _____
Manufacturer's Stated Limits

Sensor	Range	Reporting Resolution	Bias	Stabilization Criteria
Temperature				
Sp. Cond. (SC25)				
pH				
DO (Conc.)				
DO (% sat.)				
Depth – Z (pressure sensor)				

Alternative measurement sensitivity by multiple field readings
Location _____ Performed by_____
Date _____ Began calibration log _____

Sensor	1	2	3	4	5	6	7
Temperature							
Specific Conductivity (SC25)							
pH (sensor units)							
DO (Conc.)							
DO (% sat.)							
Depth – Z (pressure sensor)							

Calculations
For each parameter calculate the standard deviation of the 7 readings.

Sensor	Standard deviation	AMS 3.708x sd		
Temperature				
Specific Conductivity (SC25)				
pH (sensor units)				
DO (Conc.)				
DO (% sat.)				
Depth – Z (pressure sensor)				

Alternate Measurement Sensitivity is a two-sided estimation based on the 99% confidence interval for sample size 7. Of interest is the size of the difference between two individual values that can be considered to actually be a true difference. The MDL is a one-sided true difference from zero.

Contract Laboratory Checklist

Laboratory
Address

Contact person

_____ Received QAPP
_____ Received copy of certifications
_____ Received a list of analytical methods used
_____ Define the limits of detection and limit of quantitation calculation method
(can lab report as MDL and ML if currently calculated as LOD and LOQ?)

_____ Received a copy of latest MDL/ML/control limits calculations for relevant methods
_____ MDL/ML as listed meet project needs
(list any analyte for which the ML requirement is not met – discuss options with lab)

_____ Received successful interlaboratory participation documentation
_____ Sample handling log in and COC are documented in the QAPP
_____ Equipment maintenance and calibration procedures are documented in the QAPP
_____ Internal QA/QC documented in QAPP

Control limits calculations are made by what method
(QC includes blanks, duplicates, spikes, reference standards and LCS)

Calibration curves cover level of analytical interest
(QC includes ICV and ICB, and CCV and CCB)

Reporting data flags used include

Attach all copies

Reviewed by _____ Date _____

Attachment B

Checklists for data validation

Field Measurement Validation Checklist

(one sheet per Park sampled)

Sampling Unit _____

Date Sampled _____

Date Reviewed _____

Reviewed by _____

_____ All field forms have been received (data sheet, flow, etc.)

_____ Multiprobe was calibrated correctly

_____ Multiprobe post-calibration checks were successful

_____ Field duplicates were within range

_____ Multiprobe end of use calibration checks were successful

_____ There were no obvious trends in data taken from any sensor during the sampling day

_____ Equipment blanks sent to lab included

Laboratory Data Validation Checklist

Sample set from_____
Date taken _____
Received data _____
Reviewed by _____
Review date _____

_____ Samples received by lab at proper temperature (look at COC copy from lab)
_____ Holding time limits met
_____ Analytical methods used in analyses were those agreed upon
_____ Useable MDL and ML achieved in this analytical run
_____ Calibration procedures were followed

QC samples control limits applicable to this analytical batch

- Lab blank _____
- Lab dup _____
- Lab LCS _____
- Lab spikes _____
- Field dup _____
- Eq blank _____
- CCVs _____

QC samples within range expected

- Lab blank _____
- Lab dup _____
- Lab LCS _____
- Lab spikes _____
- Field dup _____
- Eq blank _____
- CCVs _____

Lab notes or flags

Samples rejected

Signature of Reviewer _____

Standard Operating Procedure #13: Procedure for Revising the Protocol

Version 1.0

In **Water Quality Monitoring Protocol for Inland Lakes**

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13.1 Steps for Revising the Protocol 1

Revision History Log

The following table lists all edits and amendments to this document since the original publication date. Information entered in the log must be complete and concise. Users of this standard operating procedure will promptly notify the project manager and/or the Great Lakes Network (GLKN) data manager about recommended and required changes. The project manager must review and incorporate all changes, complete the revision history log, and change the date and version number on the title page and in the header of the document file. For complete instructions, please refer to the information in this protocol, below.

Revision History Log:

Previous Version #	Revision Date	Author (with title and affiliation)	Location in Document and Concise Description of Revision	Reason for Change	New Version #
Add rows as needed for each change or set of changes tied to an updated version number					

13.0 Introduction

Because of the long-term nature of the National Park Service's monitoring program, the projects must necessarily accommodate change. Refined field methods, advances in analysis techniques, and feedback from field crews and project managers can all contribute to improving the monitoring protocol. The purpose of the current SOP is to define a systematic and routine process for incorporating these changes into the protocol.

13.1 Steps for Revising the Protocol

1. Attempt to incorporate the changes by first modifying only the SOP(s), without making changes to the protocol narrative. However, if it is clear that changes will also be needed on the narrative, then revise it as well.

2. Make all revisions using the Track Changes feature of Microsoft Word. For minor changes, at least one other person must review the revision. If the change is more extensive, a discussion of the changes by Network staff is warranted before acceptance of the revision. For major changes, review from outside of the Network should be sought. Examples of major changes include modifications of the sampling design, significantly altered field methods, and revised analysis techniques.

3. Record the changes in the revision history log of the SOP and/or in the narrative, as appropriate. Include the date of revision, full name(s) and affiliation(s) of author(s), description of and reasons for the changes, and section of SOP or narrative where changes were made.

4. Rename the version of the SOP and/or narrative. For minor changes, only revise the version number after the decimal point (e.g., change V. 1.1 to V. 1.2). For major changes, revise the number before the decimal point (e.g., V. 2.3 to 3.0). Also change the version number of the SOP or protocol in the header or footer, as appropriate.

5. Notify the data manager of the change(s) so that the metadata of the project database will be updated.

6. Distribute the revised version to all appropriate parties, including the members of the field crew and appropriate GLKN staff. The revised version must also be posted on the Network's website.

7. Maintain a library of previous versions. Such historical information may be crucial for understanding, interpreting, and analyzing data.

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