



Monitoring Protocol for Wadeable Streams of the Great Lakes Network

Version 1.0

Natural Resource Report NPS/GLKN/NRR—2017/1567



ON THE COVER

Washington Creek, Isle Royale National Park.

NPS photo / J. Elias

Monitoring Protocol for Wadeable Streams of the Great Lakes Network

Version 1.0

Natural Resource Report NPS/GLKN/NRR—2017/1567

David D. VanderMeulen¹, Joan E. Elias¹, Suzanne Magdalene², Richard Damstra¹, and Jay Glase¹

¹National Park Service
2800 Lakeshore Drive East
Ashland, Wisconsin 54806

²St. Croix Watershed Research Station
16910 152nd St. North
Marine on St. Croix, Minnesota 55047

December 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the [Great Lakes Inventory and Monitoring Network website](#) and the [Natural Resource Publications Management website](#). To receive this report in a format that is optimized to be accessible using screen readers for the visually or cognitively impaired, please email irma@nps.gov.

Please cite this publication as:

VanderMeulen, D. D., J. E. Elias, S. Magdalene, R. Damstra, and J. Glase. 2017. Monitoring protocol for wadeable streams of the Great Lakes Network: Version 1.0. Natural Resource Report NPS/GLKN/NRR—2017/1567. National Park Service, Fort Collins, Colorado.

Contents

	Page
Figures.....	vii
Tables.....	vii
Revision History Log.....	ix
Abstract.....	xi
Acknowledgments.....	xiii
List of Standard Operating Procedures	xiii
1.0 Background and Objectives	1
1.1 Rationale for Monitoring Wadeable Streams	1
1.2 Description and Historical Background of Stream Resources	2
1.2.1 Grand Portage National Monument – Grand Portage Creek.....	3
1.2.2 Indiana Dunes National Lakeshore- East Arm of the Little Calumet River.....	5
1.2.3 Isle Royale National Park – Washington and Benson Creeks.....	8
1.2.4 Pictured Rocks National Lakeshore – Miners and Hurricane Rivers	10
1.2.5 Sleeping Bear Dunes National Lakeshore – Crystal and Platte Rivers	14
1.3 Monitoring Goal & Objectives	18
2.0 Sampling Design.....	21
2.1 Review of Wadeable Stream Sampling Designs	21
2.1.1 National Monitoring Programs.....	21
2.1.2 National Park Service Network Programs.....	22
2.1.3 State Monitoring Programs.....	22
2.2 Reasons for Selecting Overall Design	23
2.3 Spatial Characterization of Monitoring Sites	24
2.4 Selection of Monitoring Variables	25
2.4.1 Biotic Indicators	26
2.4.2 Instream Habitat Assessment	27
2.4.3 Riparian Habitat Assessment.....	27

Contents (continued)

	Page
2.4.4 Water Chemistry.....	28
2.5 Sampling Frequency.....	28
2.6 Ability of Chosen Design to Meet Monitoring Objectives	28
3.0 Field Sampling Methods.....	33
3.1 Establishing Sites and Transects	33
3.2 Pre-season Preparations.....	33
3.3 Taking Field Measurements and Collecting Samples	34
3.3.1 Sequence of Activities.....	34
3.3.2 Record Field Information	36
3.3.3 Measure Water Quality Variables	36
3.3.4 Habitat Assessment	36
3.3.5 Collect and Preserve Macroinvertebrate Samples.....	37
3.3.6 Collect Periphyton Samples	38
3.3.7 Record Stage Reading/ Measure Flow	39
3.3.8 Departure from Monitoring Site.....	39
3.4 Post-Collection Procedures	39
3.5 End of Field Season Procedures	39
3.6 Quality Assurance and Quality Control	40
4.0 Data Handling, Analysis, and Reporting	43
4.1 Metadata Procedures	43
4.2 Overview of Database Design.....	43
4.3 Data Entry, Verification, Certification, and Editing.....	44
4.4 Data Archival Procedures.....	44
4.5 Quality Assurance and Quality Control Pertaining to Data Entry and Management	45
4.6 Data Analysis Procedures.....	46

Contents (continued)

	Page
4.6.1 Status	46
4.6.2 Trends	47
4.6.3 Detectable Change	47
4.7 Reporting Schedule	47
4.8 Report Format	47
5.0 Personnel Requirements and Training	49
5.1 Roles and Responsibilities	49
5.1.1 Project Manager	49
5.1.2 Field Personnel (Field Crew Member/Leader)	50
5.1.3 Data Manager	51
5.2 Crew Qualifications	51
5.3 Training Procedures	51
6.0 Operational Requirements	53
6.1 Annual Workload and Field Schedule	53
6.2 Facility and Equipment Needs	53
6.3 Startup Costs and Budget Considerations	53
6.3.1 Equipment and Initial Start-up Costs	53
6.3.2 Staff Salaries	53
6.3.3 Vehicle and Travel	53
6.3.4 Cost of Biota Identification	55
6.3.5 Total Estimated Annual Costs	55
6.4 Procedures for Revising and Archiving Previous Versions of the Protocol	55
Literature Cited	57

Figures

	Page
Figure 1. Grand Portage Creek, Grand Portage National Monument.	4
Figure 2. Little Calumet River, Indiana Dunes National Lakeshore.....	6
Figure 3. Washington Creek, Isle Royale National Park.	8
Figure 4. Benson Creek, Isle Royale National Park.....	9
Figure 5. Miners River, Pictured Rocks National Lakeshore.	11
Figure 6. Hurricane River, Pictured Rocks National Lakeshore.....	12
Figure 7. Crystal River, Sleeping Bear Dunes National Lakeshore.....	15
Figure 8. Platte River, Sleeping Bear Dunes National Lakeshore.	16
Figure 9. Schematic of sampling reach (from Fitzpatrick et al. 1998).....	25

Tables

	Page
Table 1. Length (km) of rivers and streams in GLKN parks (Lafrancois and Glase 2005, Mechenich et al. 2014).....	3
Table 2. Research and short-term monitoring conducted on Grand Portage Creek, Grand Portage National Monument (derived from Lafrancois and Glase 2005).....	5
Table 3. Research and short-term monitoring conducted on the Little Calumet River, Indiana Dunes National Lakeshore (derived from Lafrancois and Glase 2005).....	7
Table 4. Research and short-term monitoring conducted on Washington and Benson Creeks, Isle Royale National Park (derived from Lafrancois and Glase 2005).	10
Table 5. Research and short-term monitoring conducted on the Hurricane and Miners Rivers, Pictured Rocks National Lakeshore (derived from Lafrancois and Glase 2005).	13
Table 6. Research and short-term monitoring conducted on the Crystal and Platte Rivers, Sleeping Bear Dunes National Lakeshore (derived from Lafrancois and Glase 2005).	17
Table 7. Summary of national and state wadeable stream monitoring programs.	21

Tables (continued)

	Page
Table 8. Statistical power ($\alpha=0.05$) to detect 20% change, calculated from mean annual values of historically monitored water quality data from Grand Portage Creek, Little Calumet River, and Washington Creek.	29
Table 9. Number of years needed to detect 20% change at 80% power ($\alpha = 5\%$), calculated from annual values of historically monitored water quality data from Grand Portage Creek, Little Calumet River, and Washington Creek.	30
Table 10. Checklists of equipment and supplies for monitoring wadeable streams.	34
Table 11. Summary of QA/QC procedures pertaining to sampling methods.....	40
Table 12. Summary of QA/QC procedures pertaining to data management.....	45
Table 13. Expected start-up costs of wadeable streams monitoring program, including one-time purchases and routine expenses.	54
Table 14. Estimated costs for round-trip travel from GLKN headquarters to each park.	55
Table 15. Estimated total costs for monitoring streams at five park units of the Great Lakes Network.	55

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 protocol 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 #16.

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

Abstract

Small, wadeable streams are important resources in several of the park units comprising the Great Lakes Inventory and Monitoring Network (GLKN). The water quality of the streams in GLKN parks is relatively good (with some exceptions), however conditions can change rapidly. Like other waterbodies, wadeable streams face a variety of threats such as climate change, atmospheric deposition, exotic species, addition of excess nutrients and sediments, changes in surrounding land use, and increased recreation pressure. Park water resource management plans and watershed condition assessments, among other park documents, have recommended routine monitoring of streams. In this protocol, we focus our monitoring on eight wadeable streams in five parks: two streams each in Isle Royale National Park (ISRO), Pictured Rocks National Lakeshore (PIRO), and Sleeping Bear Dunes National Lakeshore (SLBE); and one stream each in Grand Portage National Monument (GRPO) and Indiana Dunes National Lakeshore (INDU), with the understanding that the protocol can be utilized at other GLKN parks. Through implementation of this protocol GLKN and park staff will: 1) monitor stream flow, chemistry, biology, and habitat, 2) assess current conditions relative to established indices and other regional data, and 3) detect trends in stream quality over time.

Acknowledgments

Wadeable streams monitoring protocols and procedures published by the U. S. Environmental Protection Agency, U. S. Geological Survey, Minnesota Pollution Control Agency, Wisconsin Department of Natural Resources (WDNR), and Michigan Department of Environmental Quality (MDEQ) were instrumental in the development of our protocol. We also drew heavily on a streams protocol published by the National Park Service Heartland Network. M. Miller (WDNR), G. Kolhepp (MDEQ), and current or former National Park Service employees D. Bowles, B. Seitz, C. Otto, P. Brown, C. Morris, and L. Kainulainen all provided valuable and constructive reviews of this protocol. Thanks also go to the following Great Lakes Inventory and Monitoring Network staff: M. Hart for drafting the data management portion of the protocol, S. Sanders for text on reporting, and T. Ledder for discussion related to field methods, sampling handling, and quality assurance/quality control.

List of Standard Operating Procedures

SOP #1: Pre-Season Preparation

SOP #2: Training and Safety

SOP #3: Using the Global Positioning System

SOP #4: Site Establishment

SOP #5: Decontamination of Equipment to Remove Exotic Species

SOP #6: Water Quality Field Measurements

SOP #7: Collection of Benthic Macroinvertebrates

SOP #8: Collection of Periphyton

SOP #9: Physical Habitat Assessment

SOP #10: Flow Measurement

SOP #11: Data Entry and Management

SOP #12: Data Analysis

SOP #13: Reporting

SOP #14: Post-Season Procedures

SOP #15: Quality Assurance and Control

SOP #16: Procedure for Revising the Protocol

1.0 Background and Objectives

Small, wadeable streams are important resources in several of the park units comprising the Great Lakes Inventory and Monitoring Network (GLKN or the Network). They serve as important connectors of the headwaters of watersheds to larger waterbodies, such as large rivers, inland lakes, or the Great Lakes. Along the route from headwaters to the confluence with a larger waterbody, wadeable streams transport and transform organic materials, such as leaves, branches, and dead organisms (Naiman et al. 2005). Such debris, becoming part of the stream via both autochthonous (within the stream) and allochthonous (outside of the stream) sources, is broken down through microbial activity into dissolved carbon (C), phosphorus (P), and nitrogen (N) and made available to the bottom of the aquatic food chain (Naiman et al. 2005).

In addition to providing dissolved and particulate organic matter, riparian areas affect adjacent lotic systems directly and indirectly in other ways. For example, the amount of canopy cover affects stream temperature; nutrient cycling and retention are affected by the amount and type of plant litter in the riparian zone; and nitrate is denitrified to nitrogen in the saturated soils alongside of the stream (Allan 1995; Hynes 2001; Naiman et al. 2005). Riparian areas are the source of coarse woody debris, which provides habitat structure for in-stream organisms (Turner and Carpenter 2005). The composition of tree species within riparian areas affects the rates of ecosystem processes, such as decomposition (Allan 1995; Turner and Carpenter 2005). Stream chemistry is influenced by biogeochemistry and hydrology within the riparian zone, size of the watershed, and surface water - groundwater exchange (Hill 2000; Holmes 2000; Mulholland and DeAngelis 2000).

Streams transport sediments, sometimes eroding banks or the stream bottom in one area and depositing the material in another area downstream (Allan 1995; Naiman et al. 2005). Streams can also transport pollutants such as fertilizers, pesticides, and road-deicing chemicals in runoff from agriculture or impervious surfaces to other waterbodies.

Healthy wadeable streams serve important ecosystem functions, such as attenuating floods, trapping sediments, processing nutrients, recharging groundwater, and fulfilling the needs of many wildlife species, both terrestrial and aquatic (Jensen and Sutton 2007). They also attract people for recreational activities, such as fishing, canoeing, swimming, and natural beauty.

1.1 Rationale for Monitoring Wadeable Streams

The water quality of the streams in GLKN parks is relatively good (with some exceptions), however conditions can change rapidly. Like other waterbodies, wadeable streams face a variety of threats such as climate change, atmospheric deposition, exotic species, addition of excess nutrients and sediments, changes in surrounding land use, and increased recreation pressure (Mechenich et al. 2006, 2009; Kraft et al. 2010). It is important to detect change as early as possible, in order to maximize the potential for effective management actions. Because preservation of water quality and quantity are 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 and Elias 2006). Park water resource management plans and watershed condition assessments, among other park documents, have recommended routine monitoring of streams (e.g., Vana-Miller 2002; Crane et al.

2006; Mechenich et al. 2006, 2009; Kraft et al. 2010). Streams and other waterbodies integrate environmental changes across terrestrial and aquatic ecosystems, and because they are particularly sensitive to change, streams can serve as sentinels of change (Williamson et al. 2008).

The key water quality concerns of wadeable streams in the GLKN include: (1) excess nutrients (particularly nitrogen and phosphorus) pathogens, and contaminants, which may come from runoff, septic systems and wastewater treatment facilities, or atmospheric deposition; (2) warming of stream temperatures, which may be caused by global climate change, changes in flow regime, or changes in riparian vegetation; (3) fluctuations in flow regime caused by climate change, industrial or residential withdrawals, increased runoff from development or other changes in surrounding land use, or channel engineering; (4) sediment loading from erosion of stream-banks and surrounding lands; (5) invasion of exotic species such as rusty crayfish (*Orconectes rusticus*) and zebra mussels (*Dreissena polymorpha*); and (6) changes in food web and habitat structure that may have ramifications throughout trophic levels.

1.2 Description and Historical Background of Stream Resources

The Network parks contain over 1,400 km of streams, rivers, and ditches (Table 1). Some of the larger rivers are not wadeable; GLKN has developed a separate protocol for monitoring water quality of the large rivers of two park units (Mississippi National River and Recreation Area and St. Croix National Scenic Riverway; Magdalene et al. (2016). Through discussions with park aquatic resource managers, we decided to target select streams of particular interest to the parks. Arguments against a probabilistic design include: 1) large portions of some stream watersheds are outside of park boundaries, 2) logistical constraints in accessing some streams, 3) budgetary and staff constraints, and 4) specific sites cannot be included in a probabilistic design unless by chance, information about individual sites would thus be sacrificed. Therefore, this protocol presupposes a targeted design and precludes random sampling of stream populations (see chapter 2 for additional aspects of design). In this protocol, we will focus on eight wadeable streams in five parks: two streams each in Isle Royale National Park (ISRO), Pictured Rocks National Lakeshore (PIRO), and Sleeping Bear Dunes National Lakeshore (SLBE); and one stream each in Grand Portage National Monument (GRPO) and Indiana Dunes National Lakeshore (INDU). The streams and rivers selected for monitoring under this protocol, grouped by park unit, are:

- Grand Portage Creek (GRPO)
- East Arm of the Little Calumet River (INDU)
- Washington Creek and Benson Creek (ISRO)
- Miners River and Hurricane River (PIRO)
- Platte River and Crystal River (SLBE)

Although the protocol focuses on the selected streams, the sampling methods are applicable to additional wadeable streams in Network parks. Descriptions of the selected lotic systems follow, including details on the reasons that the particular streams were selected.

Table 1. Length (km) of rivers and streams in GLKN parks (Lafrancois and Glase 2005, Mechenich et al. 2014).

Park Unit	Intermittent (km)	Perennial (km)	Ditches (km)	Total (km)
Apostle Islands National Lakeshore	62	20	–	82
Grand Portage National Monument	–	6	–	6
Indiana Dunes National Lakeshore	–	12	19	31
Isle Royale National Park	45	233	–	278
Mississippi National River and Recreation Area	–	123	–	123
Pictured Rocks National Lakeshore	20	114	–	134
St. Croix National Scenic Riverway	53	517	–	570
Sleeping Bear Dunes National Lakeshore	11	20	–	31
Voyageurs National Park	5	192	–	197
Total	199	1231	19	1452

1.2.1 Grand Portage National Monument – Grand Portage Creek

Approximately 1 km of Grand Portage Creek’s entire length of 10.8 km (including its two tributaries, Mt. Maud Creek and Dutchman Creek) flows within park boundaries into Lake Superior (Figure 1). The watershed (approximately 18.8 km²) is largely on the Grand Portage Indian Reservation and has been logged extensively in the past (Martin 2008). Photographs, circa 1920–1940 (Gallagher Photos), document a largely pastoral setting in the lower reaches of Grand Portage Creek, maintained in part by livestock grazing in and around the riparian corridor. Currently the watershed is mostly forested with a relatively minor amount of residential development.

Grand Portage Creek is a fast-flowing, second order stream that is subject to flash floods after substantial rains (NPS 2001). The two main tributaries of the creek are dammed, likely affecting peak flows and hydrograph duration, though the overall effects on the hydrology of the stream are thought to be minor because the impoundments are run of the river structures (Martin 2008). Along the length of the creek, stretches of riffles and small waterfalls occur. The lower reaches of the creek are used by fish from Lake Superior during times of high water and for spawning, and are important for reintroduction efforts of coaster brook trout (*Salvelinus fontinalis*) (NPS 2001).

Water quality has been monitored annually by the Grand Portage Band of Chippewa since 1999. The band has also monitored the macroinvertebrate community approximately every other year since 1999. Analysis of stream data collected from 1999–2006 within the Grand Portage Reservation indicates that median water quality conditions of Grand Portage Creek are representative of other Reservation streams, and that when state or federal reference water quality thresholds are exceeded it is likely due to local naturally-induced variation (Lafrancois et al. 2009). The U.S. Geological Survey

(USGS) developed a rating curve for Grand Portage Creek near the crossing at State Highway 61 in 1991 and collected discharge data for approximately 1.5 years. In 2013, GPRO staff and partners began to periodically monitor stream flow in the creek in order to update the rating curve.

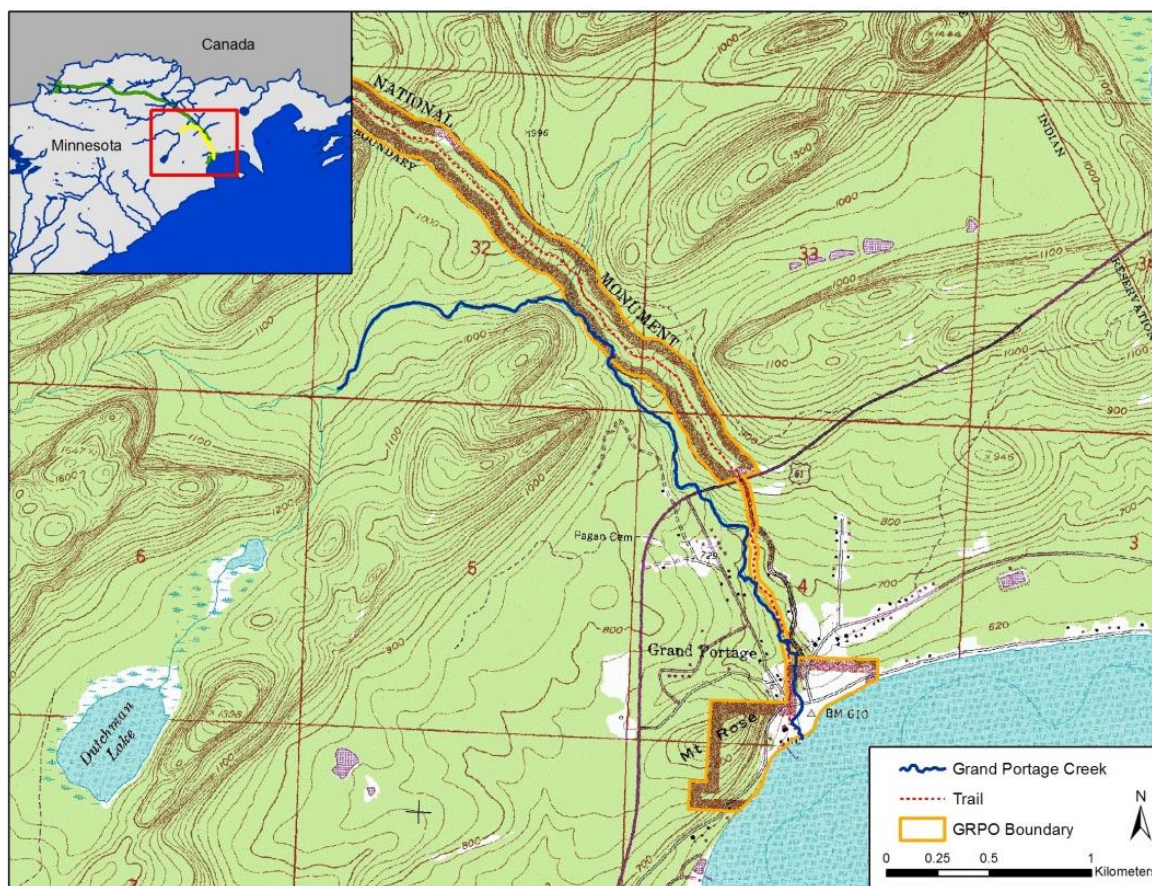


Figure 1. Grand Portage Creek, Grand Portage National Monument.

The park's resource management plan cites atmospheric deposition of mercury and PCBs as the largest threats to aquatic systems (NPS 2001). The plan also suggests that logging on Reservation lands, as well as ATV and foot trails potentially affect water quality through increased runoff and sedimentation (NPS 2001). Other potential sources of contaminants include municipal wastewater discharges, stormwater runoff, future mining operations, and recreational use (NPS 1999). More recently, discussions on the major threats to GRPO's waters have centered on aquatic invasive species, especially Viral Hemorrhagic Septicemia (VHS); sedimentation, primarily caused by changes in hydrology; the effects of climate change on streamflow, seasonal hydrology, and algal productivity; and atmospheric deposition of mercury and nitrogen (Lafrancois et al. 2009; Mechenich et al. 2014). Stream bank stabilization efforts have occurred on the lower reaches of the creek in several locations (Martin 2008), with the primary purpose being preservation of cultural resources.

Lafrancois and Glase (2005) summarized water resource studies conducted in the park over the years, providing a valuable compilation and summary of historical data. Relatively few studies have been

conducted on Grand Portage Creek, and except for the monitoring begun in 1999 by the Grand Portage Band, none have been long-term (Table 2).

Table 2. Research and short-term monitoring conducted on Grand Portage Creek, Grand Portage National Monument (derived from Lafrancois and Glase 2005).

Author, Date	Period of Record	Main Focus
Boyle & Richmond, 1997	1994–1995	Water chemistry, benthic particle size, benthic invertebrates.
Goldstein, 2000	–	Water chemistry, sediments, fish, invertebrates, algae.
Grand Portage National Monument, 2000	2000	Basic physical, chemical and biological parameters
Lafrancois et al., 2009	1999–2006	Analysis of nutrient data
National Park Service, 1999	–	Baseline water quality inventory & analysis, data retrieved from EPA databases
Newman, 1993	1992	Introduced Nipigon strain brook trout eggs and fry
Newman & Johnson, 1996	1991–1995	Brook trout hatching success monitored, eggs and swim up fry stocked
Ruhl, 1994	1992	Climate & geology, hydrology & aquifer properties, groundwater quality

1.2.2 Indiana Dunes National Lakeshore- East Arm of the Little Calumet River

All waters of INDU are designated Outstanding State Resource Waters (Ledder 2005). The threats to INDU's waters are discharges into the air and water by industry, agricultural runoff, road runoff containing road salt, leeching of landfills, settling ponds, and bacteria from human waste. Climate change is also now recognized as a potential threat to water quality and quantity.

The East Arm of the Little Calumet River flows through two units of INDU (Heron Rookery Unit and Bailly Unit) before joining the Little Calumet River at Burns Ditch and flowing out to Lake Michigan (Figure 2). Portions of the East Arm are ditched. The total length of the East Arm is approximately 36 km, with more than 12 km flowing within park boundaries (Gafvert, unpublished data). The East Arm of the Little Calumet River is a meandering, slow-flowing stream with many logjams and snags (NPS 1991). The gradient is low, though some sections of the river have steep banks (NPS 1991). Surrounding floodplain soils are poorly drained and silty; however, runoff is slow, due to the low gradient, and the bed of the river is primarily sand (NPS 1991). The watershed of the East Arm is approximately 190 km². Land use within the watershed is largely agricultural, residential, and commercial (NPS 1991).

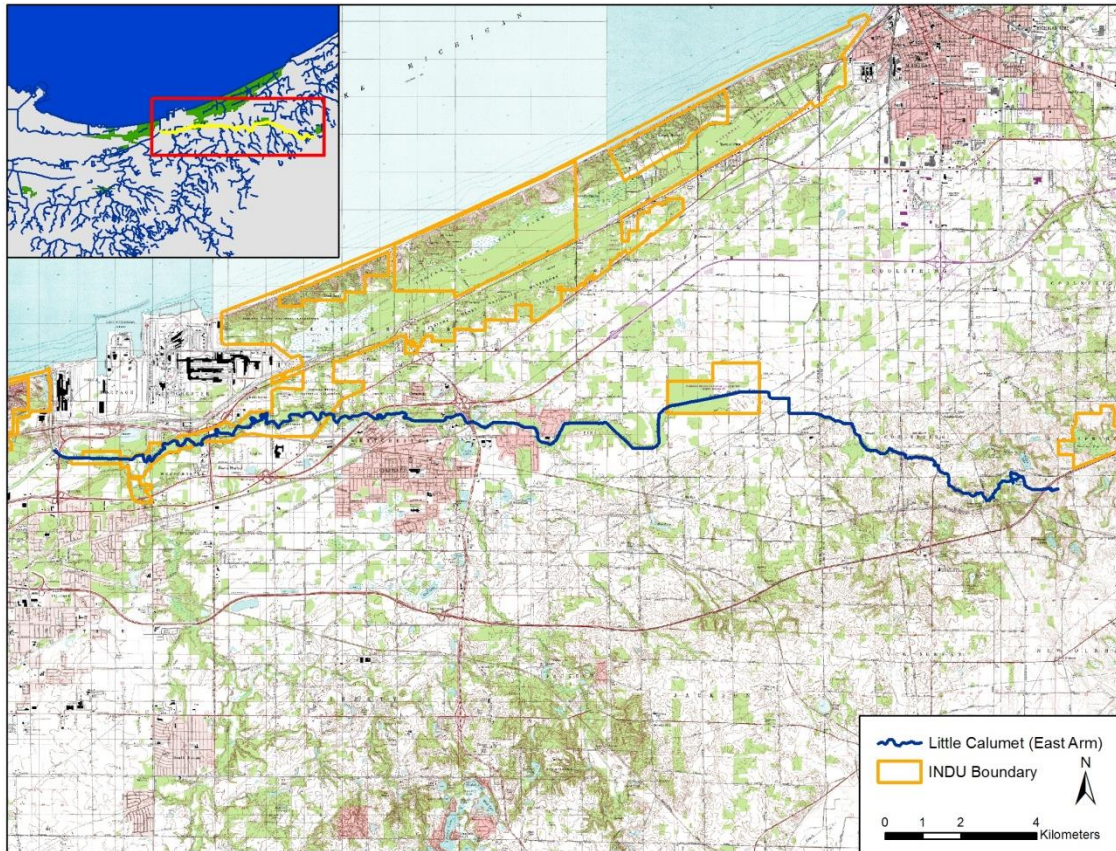


Figure 2. Little Calumet River, Indiana Dunes National Lakeshore.

The natural hydrologic processes of the East Arm have been altered by development, ditching and channelization, filling of wetlands, dewatering, and installation of dikes (NPS 1991) and the river has suffered degradation of water quality. Exceedances of U.S. Environmental Protection Agency (USEPA) impairment criteria have occurred in the Little Calumet River for fecal coliform, turbidity, dissolved oxygen, pH (both high and low), copper, lead, and *E. coli* (NPS 1994, Earth Tech 2004). In 2008, both the East Arm of the Little Calumet River and the Little Calumet River were included on the 303(d) list of impaired waters under the 1972 Federal Clean Water Act. The East Arm was listed for exceedances of PCBs in fish tissue and impaired biotic communities (www.in.gov/idem/nps/files/ir_2016_report_apndx_1_attch_4.pdf). Despite these water quality issues, the East Arm of the Little Calumet River and its tributaries are designated as cold water salmonid waters, and therefore have more stringent limits for dissolved oxygen and temperature than other waters in the park (Ledder 2003, 2005). All of the salmonid species in the river are exotic and are managed by the Indiana Department of Natural Resources (IDNR) (NPS 1991).

Lafrancois and Glase (2005) summarized water resource studies conducted in the park over the years, including several of relatively short duration that have been conducted on the Little Calumet River. These projects focused on water chemistry, stream flow, fish communities, benthic invertebrates, and contaminants (Table 3). The USGS measured a variety of parameters at a stream gage located near McCool, IN (#04095000), on the East Arm of the Little Calumet River between 1978 and 1980,

including water chemistry (organics, inorganics, nutrients, conductivity, dissolved oxygen, pH, hardness, radiochemicals), physical characteristics (temperature, discharge, turbidity), and biological taxa (phytoplankton, benthic invertebrates) (http://nwis.waterdata.usgs.gov/usa/nwis/qwdata?search_site_no=04095000). The same parameters were measured at two other nearby tributary sites without a flow gage during the same time period (B. Waters, INDU, pers. comm., 14 December 2011).

Table 3. Research and short-term monitoring conducted on the Little Calumet River, Indiana Dunes National Lakeshore (derived from Lafrancois and Glase 2005).

Author, Date	Period of Record	Main Focus
Arihood, 1975	1973–1974	Water chemistry, stream flow, insecticides in sediment, precipitation chemistry
Hardy, 1983	1978–1980	Water chemistry, periphyton, benthic invertebrates, contaminants
National Park Service, 1994	–	Baseline water quality inventory & analysis, data retrieved from EPA databases
Simon and Stewart, 1999	1985–1996	Fish community structure
Simon et al., 1998	1992–1998	Fish community structure
Spacie, 1988	1987	Fish community structure
Earth Tech, 2004	2004	Bacteria TMDL

Longer term monitoring on the Little Calumet River was conducted by the Indiana Department of Environmental Management (IDEM) and USGS (B. Waters, INDU, pers. comm., 14 December 2011). From 1971 to 1995, IDEM monitored water chemistry (temperature, dissolved oxygen, pH, conductivity, alkalinity, hardness, ammonia, total phosphorus, nitrate+nitrite-nitrogen, residue, arsenic, chromium) at one site in Porter, Indiana, approximately once or twice a month. The USGS has monitored discharge on the Little Calumet River near the Highway 20 Bridge (stream gage #4049000) since 1945, and monitored a variety of water chemistry and contaminants at the same location since 1973 (http://nwis.waterdata.usgs.gov/usa/nwis/qwdata?search_site_no=04094000). The USGS has also monitored water chemistry and select contaminants from circa 1990 to 2004 at sites just above and below (now referred to as Burns Ditch) the confluence with the west branch of the Little Calumet River and at two sites on Salt Creek, a tributary to the Little Calumet River from 1991 to 2004.

Currently, no long-term monitoring is being conducted on the East Arm of the Little Calumet River, although GLKN staff completed preliminary water quality monitoring at the Howe Road Bridge near park headquarters in 2007 and 2008. A TMDL study completed in 2004 (Earth Tech 2004) identified the need to coordinate long-term monitoring among agencies, and establish long-term monitoring

sites upstream of Chesterton due to a lack of water quality information in the headwaters of the East Arm of the Little Calumet River.

1.2.3 Isle Royale National Park – Washington and Benson Creeks

All waters of ISRO are designated by the State of Michigan as Outstanding State Resource Waters (OSRW). This designation is meant to protect waters from degradation in quality from anthropogenic actions. Additionally, both Washington and Benson Creeks are designated as trout streams, which mean that under State guidelines they are protected as cold water fisheries, and must maintain a dissolved oxygen concentration of ≥ 7 mg/L. However, because the State has no jurisdiction over inland water at ISRO, the designations are not enforceable and serve only as recommendations for park management.

Washington Creek is approximately 10.5 km in length, all of which flows within the park (Figure 3). The 35 km² watershed is forested. The creek has experienced exceedances of EPA criteria for pH (once in 1965); total and fecal coliform approximately 10%–15% of sampling dates; and occasionally, cadmium, copper, lead, and zinc, though these exceedances were attributed to natural causes (NPS 1995; Crane et al. 2006).

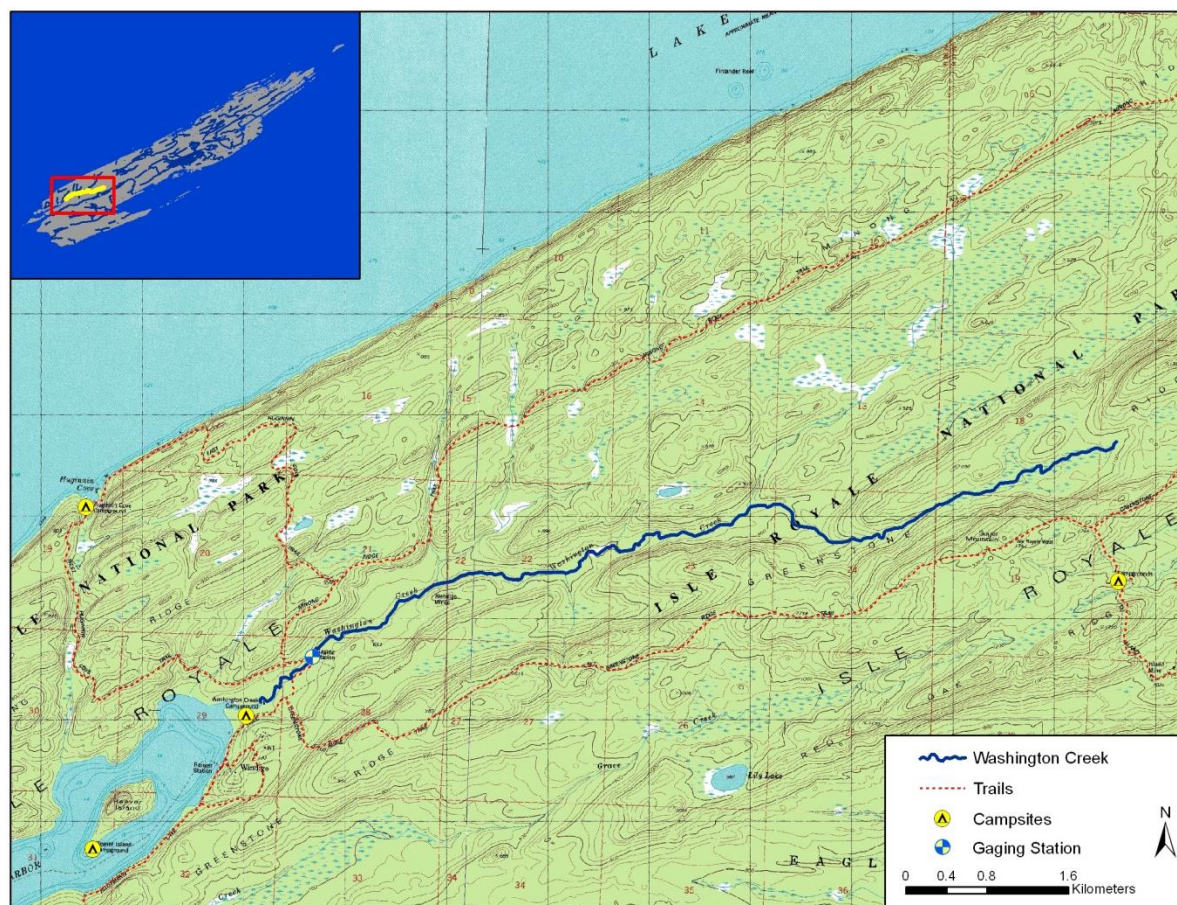


Figure 3. Washington Creek, Isle Royale National Park.

Benson Creek, approximately 2.5 km in length, drains a relatively small, forested watershed (approximately 2.2 km²), and like Washington Creek, is entirely contained within park boundaries (Figure 4). The creek runs alongside the Daisy Farm campground, and empties into Lake Superior in Rock Harbor.

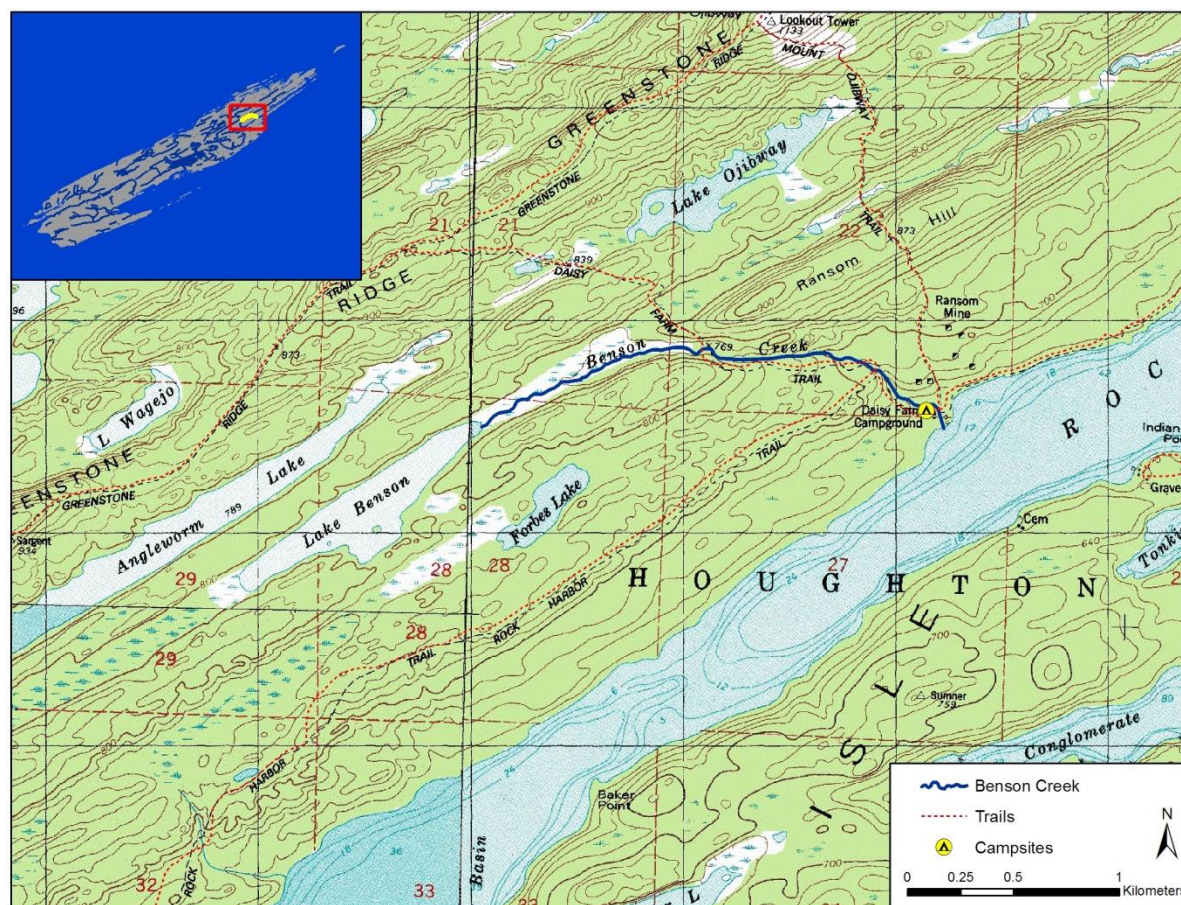


Figure 4. Benson Creek, Isle Royale National Park.

Threats to these two creeks are primarily from atmospheric deposition, exotic species, and climate change (Crane et al. 2006), although wastewater discharge and fuel spills from recreational boats and shipping on Lake Superior could threaten the mouths of the creeks. The privies for the campground located along Benson Creek may pose an additional threat of bacterial contamination, as Meldrum (1987) found evidence of fecal coliform from human sources in the mid-1980s.

Lafrancois and Glase (2005) summarized water resource studies conducted in the park over the years, providing a valuable compilation and summary of historical data. Only a few studies have been conducted on Washington Creek (Table 4) and most of these have been of relatively short-term duration. One notable exception is the stream gage (stream gage # 04001000) installed and maintained by the USGS from 1964 to 2003, and 2010 to present, providing continuous flow and temperature data and occasional water chemistry data

(http://nwis.waterdata.usgs.gov/nwis/qwdata?search_site_no=04001000). Recently, the U.S. Fish and

Wildlife Service (USFWS) began monitoring temperature in both Washington and Benson Creeks, with an interest in habitat suitability of the creeks for coaster brook trout (*Salvelinus fontinalis*). Other than this temperature monitoring and the bacterial study in the 1980s, little work has been conducted on Benson Creek.

Table 4. Research and short-term monitoring conducted on Washington and Benson Creeks, Isle Royale National Park (derived from Lafrancois and Glase 2005).

Author, Date	Period of Record	Main Focus
Bowden, 1981	1979	Washington - water chemistry, discharge, macroinvertebrates
Carlisle, 2002	2001	Washington - macroinvertebrates, sediment, water chemistry, leaf-litter breakdown, stream habitat
Mast & Turk, 1999	1967–1969 1970–1982 1983–1995	Washington - water chemistry, hydrology, trend analysis
Meldrum, 1987	1984–1985	Benson – bacteria
National Park Service, 1995a	–	Baseline water quality inventory & analysis, data retrieved from EPA databases
Slade, 1995	1994	Washington - coaster brook trout spawning locations
Slade & Olson, 1994	1993	Washington - community structure of stream fish
Stottlemeyer, 1982	1980–1985	Washington - precipitation chemistry, stream gages installed, water chemistry, snow accumulation
Toczydlowski, 1978	Summer	Washington - water chemistry, phytoplankton, aquatic insects, aquatic plants

1.2.4 Pictured Rocks National Lakeshore – Miners and Hurricane Rivers

All waters of PIRO have been designated by the State of Michigan as OSRW. This designation protects these waters from degradation in quality from anthropogenic actions. Additionally, both the Miners and Hurricane Rivers are designated as trout streams, and as such, are protected as cold water fisheries. Designated trout streams must maintain stricter standards for dissolved oxygen concentration and temperature than waterbodies with other designations.

Both rivers originate outside of park boundaries, flow through the Inland Buffer Zone (IBZ; land owned by corporate, state, federal, and private entities and designated to protect the watersheds within the park; timber harvesting is allowed in the IBZ) and park-owned land, and empty into Lake Superior. They are second order streams, and are flashy, with discharge responding quickly to heavy rainfall or snowmelt (Loope 2004). The area was logged extensively in the past, though the watersheds of both streams are now forested (Meichenich et al. 2006).

At approximately 20 km in length, the Miners River is the park's longest river; 12 km of the total length flows within park boundaries (Gafvert, unpublished data; Figure 5). The NPS has included a 14 km section of the river as eligible for designation as a National Wild and Scenic River. The stream has a steep overall gradient, with a waterfall, numerous riffles, and a cascade; these are punctuated by extensive, low gradient reaches (Loope 2004). The USFWS maintains a sea lamprey (*Petromyzon marinus*) weir within the park to monitor presence and timing of sea lamprey spawning, and to prevent migration upstream, where the substrate of Miners Lake is ideal nursery habitat for sea lamprey. The watershed of the river is approximately 69 km² (Gafvert, unpublished data) and is largely forested.

Approximately 7 km of the Hurricane River's total length of over 10 km flows within park boundaries (Gafvert, unpublished data; Figure 6). The river has a relatively low gradient upstream of Hurricane Falls, which is near the mouth. The watershed is largely forested, with headwaters in sedge meadows, and encompasses approximately 33 km².

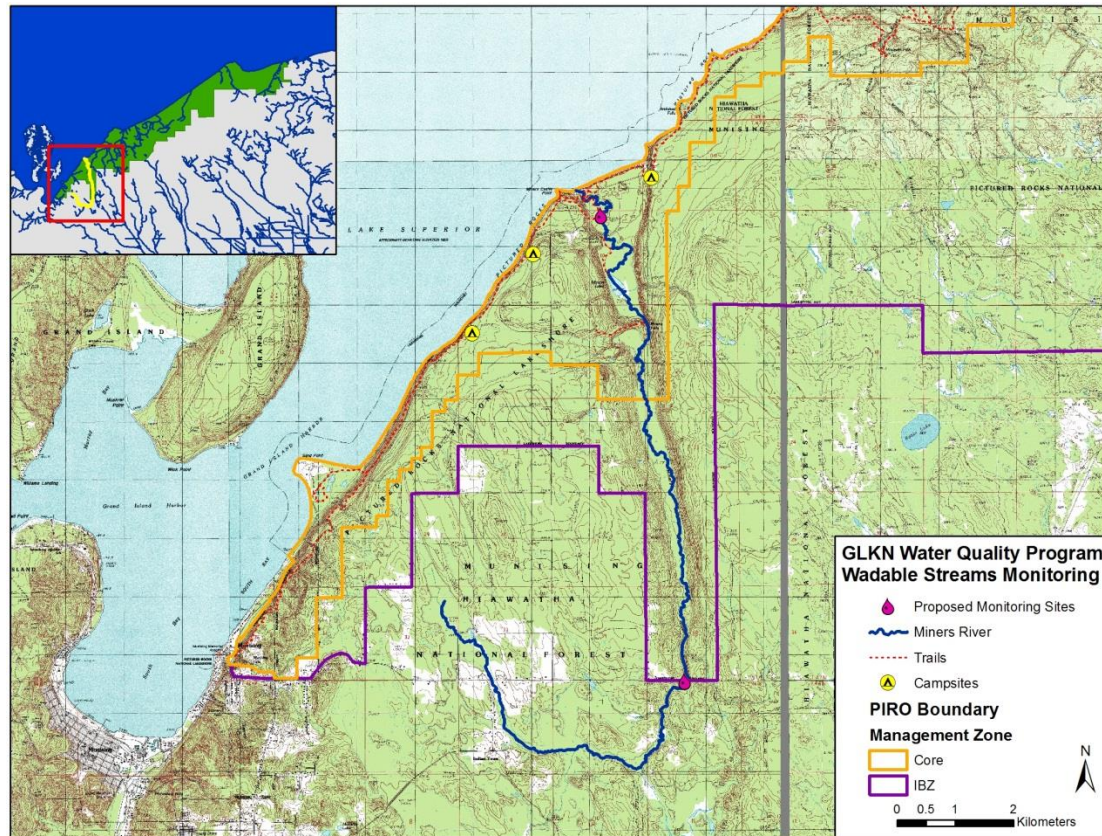


Figure 5. Miners River, Pictured Rocks National Lakeshore.

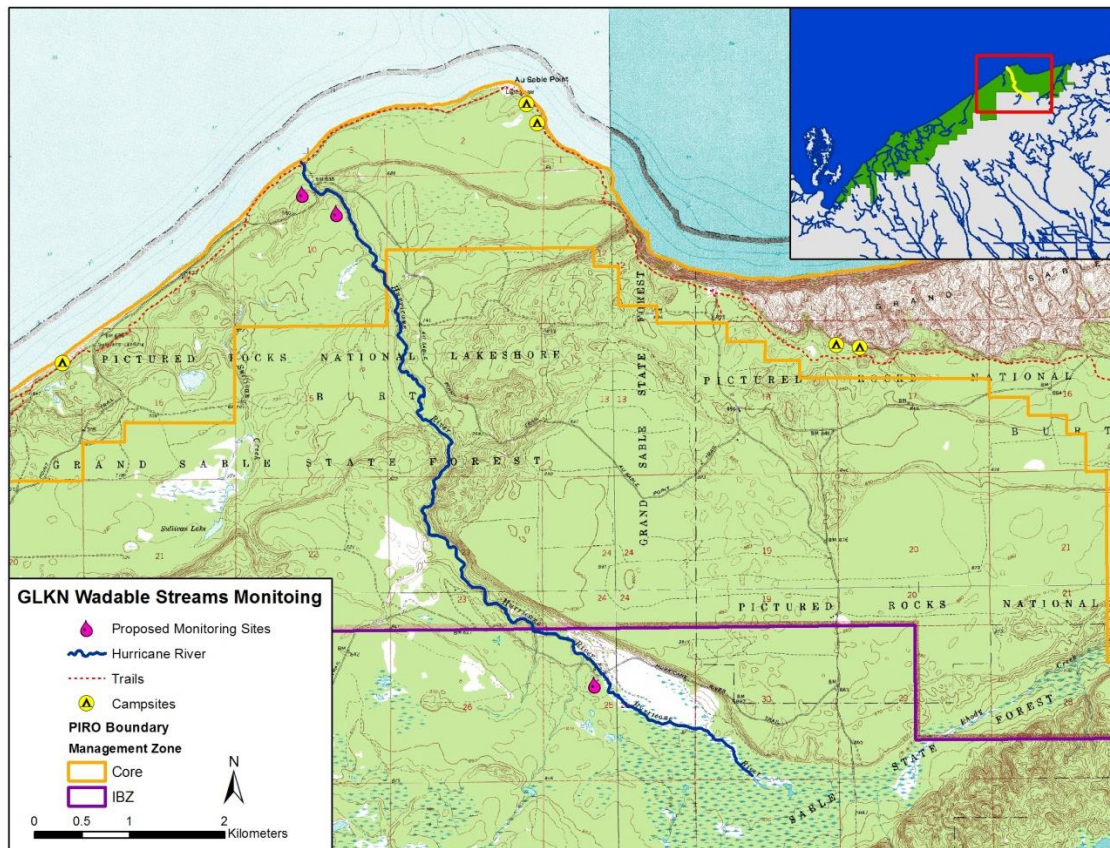


Figure 6. Hurricane River, Pictured Rocks National Lakeshore.

The primary threats facing both the Miners and Hurricane Rivers are land use practices in the IBZ and outside of the park, such as road building and timber harvesting that may cause increased runoff and sedimentation; development near the park; atmospheric deposition; and invasive species (NPS 2003; Mechenich et al. 2006). Climate change is also widely recognized as a potential stressor, with potential impacts on hydrology and stream temperatures. Excess nutrients from human waste from backcountry campgrounds and septic systems in the IBZ are another potential stress (Loope 2004). Exceedances of EPA criteria have not been observed on either river (NPS 1995b).

Lafrancois and Glase (2005) and Mechenich et al. (2006) summarized water resource studies conducted in the park over the years (Table 5). These two syntheses provide valuable compilations and interpretations of historical data upon which, along with discharge data collected by the park, the GLKN wadeable stream monitoring program can build. The Michigan Department of Environmental Quality has collected data on fish, invertebrates, water chemistry, habitat, and discharge on at least one occasion in both rivers (Hurricane River: www.mcgi.state.mi.us/miswims/results.aspx?searchType=GNISID&id=00628883&searchTerm=Hurricane%20River:%20Alger%20County; Miners River: www.mcgi.state.mi.us/miswims/results.aspx?searchType=GNISID&id=01620843&searchTerm=Miners%20River:%20Alger%20County; search on the “water quality” tab). Previous to the State’s responsibilities under the Clean Water Act, the Michigan Department of Conservation (later renamed

as the Michigan Department of Natural Resources) periodically assessed fish populations and physical attributes of Miners and Hurricane Rivers, recorded in Stream Fish Collection data sheets (Michigan Department of Conservation 1953–1980).

Assessments of Hurricane River and Miners River initiated regular monitoring of discharge beginning in 1994 and 1995, respectively (Boyle et al. 1999). In addition, they also quantified substrate, water depth, bankfull, large woody debris, and identified and enumerated macroinvertebrates at numerous stations along the rivers (Boyle et al. 1999). Since then, park staff have monitored discharge at the mouths of the Hurricane and Miners Rivers. With few exceptions, measurements are taken several times a year in the open water season. In 2016, USGS established a stream gauge (#04044755) on the Miner’s River (http://waterdata.usgs.gov/mi/nwis/uv/?site_no=04044755&PARAMeter_cd=00065,00060).

Since 1997, an increased interest in coaster brook trout (*Salvelinus fontinalis*) has arisen at PIRO. Researchers at Northern Michigan University have conducted research on fish movements in the Hurricane River since 2003, along with data on the physical characteristics of both rivers (Stimmell 2006; Leonard et al. 2007; Kusnierz 2008; Kusnierz et al. 2009).

In conclusion, despite the previously-mentioned studies, relatively few short-term and virtually no long-term studies or projects have been conducted on the Miners and/or Hurricane Rivers.

Table 5. Research and short-term monitoring conducted on the Hurricane and Miners Rivers, Pictured Rocks National Lakeshore (derived from Lafrancois and Glase 2005).

Author, Date	Period of Record	Main Focus
Boyle et al., 1999	1994–1996	Hurricane & Miners - water chemistry, risk assessment, substrate size/character, macroinvertebrates, fish
Daes, 1991	Oct 1989, 1990	Aerial surveys for beaver and muskrat
Gervac & Whitman, 1995	Summer 1995	Hurricane & Miners - fish surveys
Handy & Twenter, 1985	1979–1981	Hurricane & Miners - water chemistry, stream drainage area, discharge, groundwater quantity & quality, compare above & below Miners Lake
Limnetics, Inc., 1970	One sampling event/stream	Hurricane & Miners - water chemistry, phytoplankton, zooplankton, macroinvertebrates, sediment quality
Loope and Holman, 1991	1986	Hurricane & Miners - stream physical habitat, aquatic & streamside vegetation
Loope and Scott, 1987	1987	Miners - stocked grayling (<i>Thymallus arcticus</i>)
National Park Service, 1995a	–	Baseline water quality inventory & analysis, data retrieved from EPA databases

Table 5 (continued). Research and short-term monitoring conducted on the Hurricane and Miners Rivers, Pictured Rocks National Lakeshore (derived from Lafrancois and Glase 2005).

Author, Date	Period of Record	Main Focus
Newman, 2001	One sample/ stream, 1998	Fish assessment
Nichols et al., 2001	1999–2000	Hurricane & Miners - mussel surveys, contaminants in soft tissues; physical habitat
Pictured Rocks National Lakeshore and Michigan Department of Natural Resources, 1995b	–	Fisheries management plan
Stimmel, 2006	2003–2005	Hurricane - fish, coaster brook trout stocking, coaster brook trout movements, water temperature
Kusnierz, 2008	2007–2008	Hurricane – fish, coaster brook trout movements
Kusnierz et al., 2009	2003–2008	Hurricane – fish, coaster brook trout movements
Mich. Dept Conserv., 1953–1980	1953–1980	Hurricane & Miners (data not annual) – fish community structure

1.2.5 Sleeping Bear Dunes National Lakeshore – Crystal and Platte Rivers

All waters of SLBE are designated as OSRW by the State of Michigan. This anti-degradation policy defines these waters as high quality or important ecologically, and protects them from degradation due to anthropogenic actions. Both the Crystal and Platte Rivers are designated trout streams, and as such are under stricter guidelines for dissolved oxygen concentrations and temperature. Both rivers receive substantial inputs of groundwater (Vana-Miller 2002; Lafrancois and Glase 2005), and both rivers experience high recreational pressures from people kayaking and fishing. The Platte River also gets high numbers of people tubing the lower reaches.

The Crystal River totals 10 km in length, approximately 4.5 km of which flows within park boundaries (Gafvert, unpublished data; Figure 7). It is a fourth order stream originating in Fisher Lake, outside of park boundaries (Vana-Miller 2002). Within the park, the river flows out of Glen Lake, where a small, private dam regulates its flow. The regulation of the water level of Glen Lake and the amount of flow allowed to pass downstream has been controversial over the years (Vana-Miller 2002). The controversy centers on adequate water levels in the lake to accommodate shoreline property owners' recreational activities, versus adequate flow in the river to sustain aquatic life and recreation (Vana-Miller 2002).

The Crystal River watershed encompasses approximately 120 km², with land uses including a mix of agriculture, forested, and residential development. While a variety of potential stressors (e.g., excess nutrients and sediments from runoff and septic systems, atmospheric deposition, exotic species, climate change) may threaten the water quality of the river, the current issue of primary concern is

adequate flow to sustain aquatic life and recreational activities (S. Yanch, SLBE, pers. comm., 12 December 2011). Although classified as a cold water stream (Meichenich et al. 2009) water temperatures in summer reach highs in excess of 25°C, perhaps due to the low flow conditions.

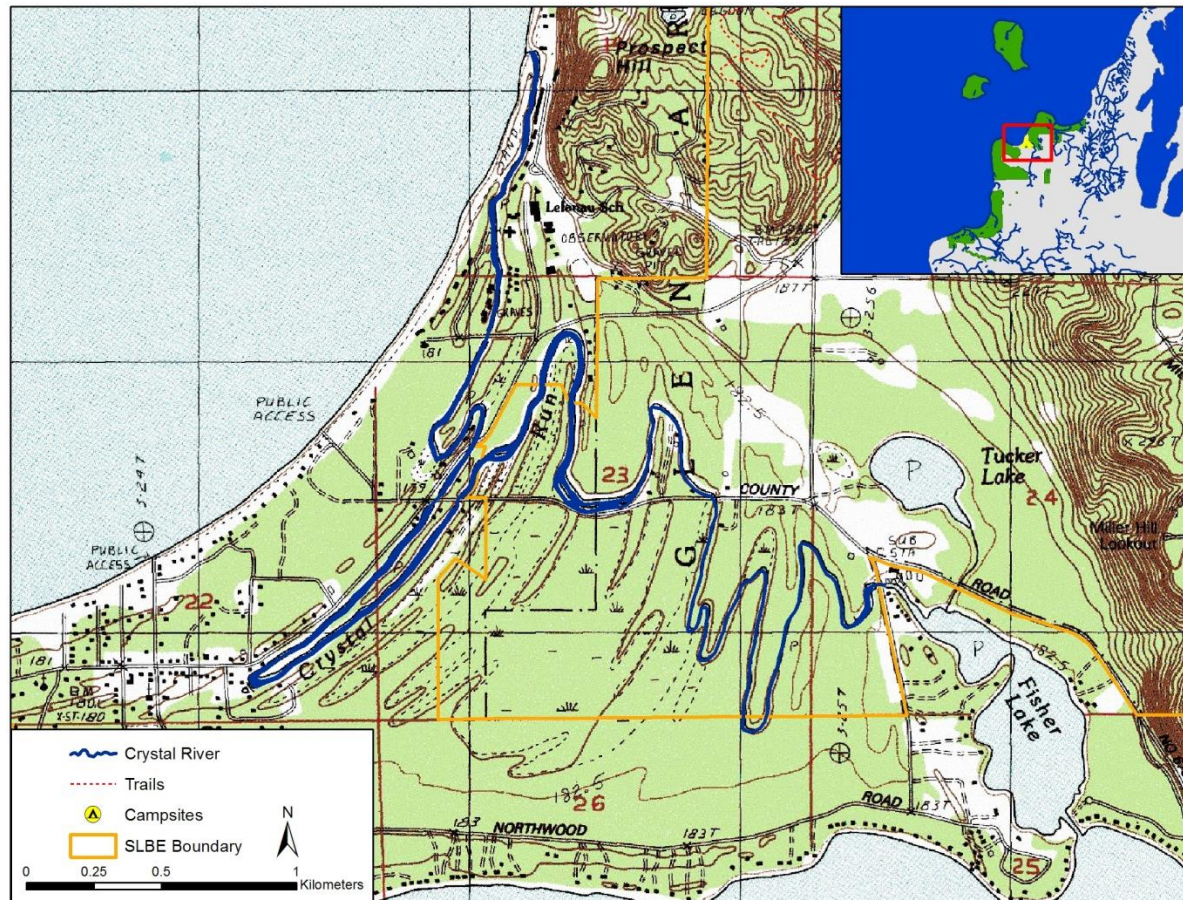


Figure 7. Crystal River, Sleeping Bear Dunes National Lakeshore.

Approximately 8 km of the Platte River's total length of nearly 55 km flows within park boundaries (Gafvert, unpublished data; Figure 8). The river's watershed encompasses approximately 380 km². Land uses within the watershed are predominantly agricultural, forested, and residential. The same array of potential stressors threatens the Platte River as those listed above for the Crystal River, but the issue of primary concern to the park is the level of visitor use and associated impacts (S. Yanch, pers. comm., 12 December 2011). The Platte River has exceeded EPA water quality criteria for cadmium and total coliform (NPS 1997).

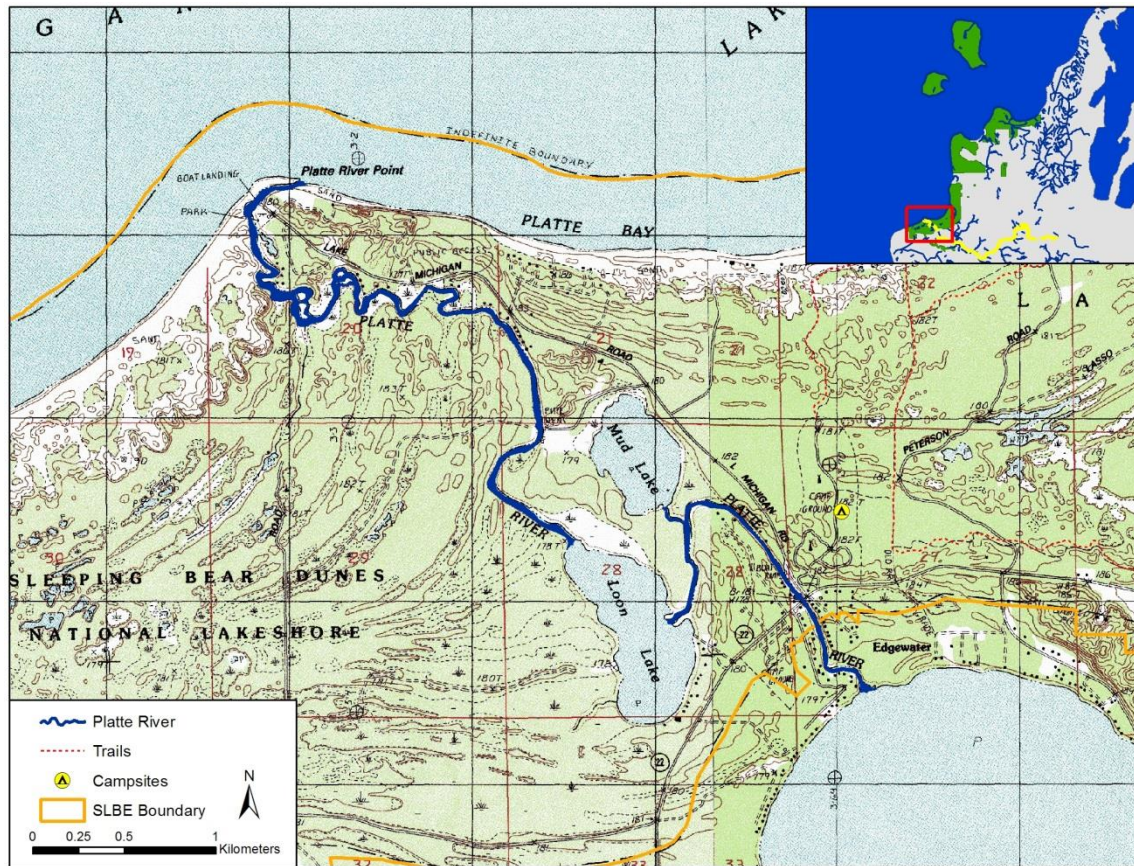


Figure 8. Platte River, Sleeping Bear Dunes National Lakeshore.

The portion of the Platte River that lies within park boundaries is classified as a cool water river, though the entire river has an unusual temperature regime (Fessel 2007). The headwaters of the river are fed by warm lake water. Temperature is then cooled by a substantial input of groundwater downstream, only to be warmed again by lake water in Platte and Little Platte Lakes prior to reaching the park boundary (Fessel 2007). The state operates a fish hatchery upstream of the park, primarily rearing exotic salmonids, such as Chinook salmon (*Oncorhynchus tshawytscha*) and Coho salmon (*Oncorhynchus kisutch*). In years past, the hatchery has released excessive nutrients into the river, but this problem has been rectified (Lafrancois and Glase 2005).

Lafrancois and Glase (2005) and Mechenich et al. (2008) summarized water resource studies conducted in the park over the years. These two syntheses provide valuable compilations and interpretations of historical data upon which the GLKN wadeable stream monitoring program can build. A considerable number of short-term studies and projects that included the Platte and/or Crystal Rivers have been conducted at SLBE (Table 6), but few long-term monitoring projects have been undertaken, with the following notable exceptions.

The USGS has maintained a stream gage on the Crystal River within park boundaries since 2003 with funding from the Glen Lake Association (http://waterdata.usgs.gov/mi/nwis/measurements/?site_no=04126801&). A nearby gage

(#04126802) collected daily data on temperature, discharge, and specific conductance from 2003 to 2006, and data on pH and dissolved oxygen from 2004 to 2006. The gage was decommissioned in 2006. Michigan DEQ conducted habitat, fish, and/or macroinvertebrate surveys at several sites, once each since 1998

(www.mcgi.state.mi.us/miswims/results.aspx?searchType=GNISID&id=01617974&searchTerm=Crystal%20River:%20Leelanau%20County; search on “water quality” tab).

Table 6. Research and short-term monitoring conducted on the Crystal and Platte Rivers, Sleeping Bear Dunes National Lakeshore (derived from Lafrancois and Glase 2005).

Author, Date	Period of Record	Main Focus
Albert, 1992	1991	Aquatic macrophytes, water depth, substrate characteristics
Albright et al., 2002	–	Crystal - hydrology
Boyle & Hoefs, 1993	1990–1992	Platte - water chemistry, discharge, benthic invertebrates
Canale, 2002	–	Platte - hatchery operations, tributary flows, phosphorous levels
Curry, 1973	1972	Crystal - water chemistry, bacteria, plankton, bottom fauna
Curry, 1977	1972	Crystal - water chemistry, chironomids, aquatic vascular plants
Environmental Resources Management 1985	1983–1984	Platte - mouth dynamics, macroinvertebrates before/after dredging, visitor use
Fessel, 2007	–	Crystal & Platte - fisheries surveys
Flower & Walker, 1999a	1998	Crystal - fish, water chemistry, macroinvertebrates, habitat
Flower & Walker, 1999b	1998	Platte - water chemistry, fish, macroinvertebrates, habitat
Hazlett, 1989	1986, 1987	Macrophytes
Heiman & Woller, 2003	–	Crystal - watershed management plan
Heuschele, 2000	–	Crystal & Platte - biomonitoring recommendations
Hoefs, 1993	1992	Platte - invertebrate communities; impacts of gasoline leak
Kelly & Price, 1979	–	Crystal & Platte - fisheries surveys
Linton, 1987	–	Crystal & Platte - temperature, pH, current velocity; habitat description; macroinvertebrates
MiDEQ, 1999	1998	Platte - water chemistry, biological, physical habitat

Table 6 (continued). Research and short-term monitoring conducted on the Crystal and Platte Rivers, Sleeping Bear Dunes National Lakeshore (derived from Lafrancois and Glase 2005).

Author, Date	Period of Record	Main Focus
Murphy, 2001	2000–2001	Crystal - water chemistry, macroinvertebrates
National Park Service, 1997	–	Baseline water quality inventory & analysis, data retrieved from EPA databases
Stockwell & Gannon, 1974, 1975	1973, 1974	Platte - water chemistry, watershed soils, land cover, hydrology, benthic invertebrates, macrophytes
Taube, 1974	–	Platte - physical, chemical, biological characteristics; salmonid history
University of Michigan Biological Station, 1975	1967–1972	Platte - summary of fish surveys
Vana-Miller, 2002	–	Water resources management plan
Walker, 1998	1990s	Platte - watershed phosphorus loading models
White, 1987	1987	Crystal & Platte - macroinvertebrates
Whitman et al., 1994	1994	Crystal & Platte- water chemistry, invertebrates

A USGS gaging station (#04126740) is located on the Platte River upstream of the park, near Honor, Michigan. Discharge has been measured at this gage since 1990

(http://nwis.waterdata.usgs.gov/nwis/inventory/?site_no=04126740). The Michigan Department of Environmental Quality has monitored contaminants in fish tissue at five sites and environmental parameters at 24 sites along the Platte River

(www.mcgi.state.mi.us/miswims/results.aspx?searchType=GNISID&id=00635085&searchTerm=Platte%20River; search on “water quality” tab). At one of these sites, located within park boundaries, contaminants in fish tissues were measured from 1978 to 1981, and water chemistry, including some contaminants in water, was monitored from 1968 to 1975.

1.3 Monitoring Goal & Objectives

Our overall goal is to monitor the quality of these wadeable streams in order to contribute to an understanding of the ecological integrity of park units of the Great Lakes Network. We want to assess current conditions relative to established indices and other regional data, and we want to be able to detect trends (directional change, as distinguished from the natural range of variability) in stream quality over time. Specific objectives are:

1. Monitor stream flow using existing USGS stream gages to determine annual and seasonal means, flashiness, and timing and duration of peak flow. Analyze for change over time.

2. Monitor water temperature to determine diurnal, seasonal, and annual variability; annual and seasonal means; timing and duration of maximum temperatures. Analyze data for change over time. Summarize data relative to current stream designations (e.g., cold water fishery).
3. Monitor macroinvertebrates, periphyton, and habitat characteristics to assess current stream conditions and analyze for change over time. Relate the biotic communities to overall water quality through quantification of metrics related to species richness, abundance, diversity, and region-specific indices as indicators of water quality and habitat condition.
4. Relate observed changes in flow, chemistry, biology, and habitat to surrounding land use, climate, and air quality data acquired from other sources.

2.0 Sampling Design

While the primary objective of thoughtful sampling design is to provide statistical robustness and scientific rigor, we acknowledge that additional factors must be considered. This wadeable streams sampling design was developed through a process that included discussions with park resource managers, statistical analysis of historical water quality data, and evaluation of logistical and fiscal considerations. For any natural resource monitoring protocol, the key aspects of sample design are 1) physical sampling frame (spatial boundaries of the resource), 2) sites (selection criteria, numbers, and locations), 3) variables, and 4) temporal sampling frame (sampling and return frequencies). Chapter 1 of this protocol narrative has detailed the physical sampling frame and site selection criteria of this protocol; this chapter addresses the remaining aspects of sample design, and to what extent the chosen sample design is expected to achieve the monitoring objectives outlined in chapter 1.

2.1 Review of Wadeable Stream Sampling Designs

In order to choose a sample design that would achieve our stated objectives, we first evaluated the established monitoring protocols for wadeable streams that are administered by national programs, other NPS networks, and state monitoring programs in which GLKN parks are located: Minnesota, Wisconsin, Michigan, and Indiana (summarized in Table 7). Although we have selected a targeted design, we included protocols of randomized design in this evaluation, so as to compare all aspects of sample design for wadeable streams.

Table 7. Summary of national and state wadeable stream monitoring programs.

Program Detail	USGS	EPA	NPS	MN	WI	MI	IN
Purpose	Natural & human impacts	Status, future trends	Status, future trends	Status	Status	Status	Status, future trends
Design	targeted	random	both	random	random	both	both
Revisit frequency	varies	–	3 yrs	–	–	5 yrs	5 yrs
In-situ water quality	X	X	X	X	X	X	X
Invertebrates	X	X	X	X	X	X	X
Fish	X	X	–	X	X	X	X
Periphyton	X	X	–	–	–	–	–
Habitat	X	X	X	X	X	X	X

2.1.1 National Monitoring Programs

The USGS National Water Quality Assessment program (NAWQA) aims to provide an understanding of the nation's water quality conditions, whether conditions are getting better or worse over time, and how natural features and human activities affect those conditions. A targeted sample

design is used to assess the degree to which water quality is degraded. Using nationally-consistent protocols (<http://water.usgs.gov/nawqa/protocols.html>), water quality monitoring data are integrated with geographic information on hydrological characteristics, land use, and other landscape features in models to extrapolate an understanding of water quality conditions to unmonitored areas. Wadeable streams protocols include field-measured water quality (Wilde 2008), stream habitat (Fitzpatrick et al. 1998), algae, invertebrates, and fish (Moulton et al. 2002).

The USEPA Wadeable Streams Assessment program uses a probabilistic sample design to assess the current ecological status of the nation's wadeable streams and rivers, and to enable future trends analysis (USEPA 2006). First- through fifth-order perennial streams within nine ecoregions were selected as the sample population (96% of the nation's stream miles), and each of the 1,392 randomly-selected sites was sampled once using rapid bioassessment protocols (Barbour et al. 1999). Thus far, the program has conducted sampling during two monitoring periods (summer months during 2000–2004 and 2013–2015). Each site was evaluated for in-situ water chemistry, physical habitat, periphyton on substrates, and fish; benthic macroinvertebrates were collected from 11 transects. Finally, sites were compared to least-disturbed reference sites within each ecoregion and assigned to a condition quality grouping of poor (<5th-percentile), fair (5th- to 25th-percentile), or good (>25th-percentile), based on their comparison to regional reference conditions.

2.1.2 National Park Service Network Programs

As part of the National Park Service Inventory and Monitoring Program, many networks have developed or are developing protocols to monitor various aspects of streams. For example, the Heartland Network focuses on macroinvertebrates, physical habitat, and water chemistry in small prairie streams of the central plains and large rivers and their tributaries (Bowles et al. 2007, Bowles et al. 2008); the Upper Columbia Basin Network of the Northern Cascades assesses physical, chemical, and biological metrics of stream quality (Starkey et al. 2008); and the Sonoran Desert Network includes stream channel morphology, riparian vegetation, water quality and quantity, and several biotic components in perennial desert streams (McIntyre et al. 2009).

2.1.3 State Monitoring Programs

The Minnesota Pollution Control Agency (MPCA) has used benthic invertebrates as indicators of human disturbance of aquatic resource integrity for 25 years. The MPCA Biological Monitoring Program uses a multi-habitat sampling approach. Genet and Chirhart (2004) developed a macroinvertebrate index of biotic integrity (MIBI) for all permanent coolwater rivers and streams within the Upper Mississippi River Basin (UMRB). A qualitative multi-habitat (QMH) sample is collected at each site to characterize the overall macroinvertebrate diversity of the sample reach. During this evaluation the following habitats are considered: 1) riffles or shallow, fast flowing runs, 2) undercut banks and overhanging vegetation, 3) submerged or emergent aquatic macrophytes, 4) snags and woody debris, and 5) leaf packs. Niemala et al. (2004) used an integrated monitoring approach that combined measures of habitat, water chemistry, and fish and/or invertebrate community structure to assess 50 randomly-selected sites (cf., EPA-EMAP) in the Minnesota portion of the St. Croix River Basin. This approach is now utilized statewide to conduct probabilistic rivers

and streams survey every five years, randomly sampling 150 stations divided equally across the state's three major eco-regions.

Stream ecologists at the Wisconsin Department of Natural Resources (WDNR) were pioneers in the development of macroinvertebrate indices (Hilsenhoff 1977). In 2005, following an EPA-EMAP-funded regional assessment, the WDNR's Baseline Wadeable Streams Monitoring Program began employing probabilistic sampling of four stream classes (combinations of cold/warm, small/large) to assess Wisconsin's stream populations. Since then WDNR's wadeable stream monitoring has expanded to include 1) reference streams that depict least-disturbed conditions, 2) sites chosen randomly, to infer state-wide stream conditions, 3) streams within a specific watershed, and 4) streams that are of special interest to volunteers (WDNR 2015). Specific to the streams monitored through the random selection design, macroinvertebrates, collected with a kick net from a single riffle, are used to monitor small streams (first- and second-order; Lillie et al. 2003). In addition to macroinvertebrate sampling, large stream (> second-order) monitoring includes in-situ water quality measurements (temperature, pH, conductivity, dissolved oxygen, turbidity), fish sampling, and assessment of fish habitat.

The Michigan Department of Environmental Quality (MiDEQ) uses a qualitative method to assess and detect spatial and temporal trends in wadeable streams of major watersheds on a minimum of a five-year cycle. The development of this biosurvey protocol resulted from increasing demand for a more rigorous and standardized evaluation of nonpoint source impacts. MiDEQ employs similar protocols for both targeted (MiDEQ 2008) and probabilistic (Fore and Yoder 2003) sample designs. The protocols call for sampling in a low-to-moderate flow regime during June-September, and include calculating multiple metrics for fish, macroinvertebrates, and habitat quality. The accuracy of the protocol, however, depends on the selection and evaluation of reference sites for baseline comparison. Reference sites of excellent quality are selected by biologists from streams within each of Michigan's ecoregions. These sites then become the recommended standard against which all other stream metrics are compared.

The Indiana Department of Environmental Management (IDEM) Watershed Assessments Program is designed both to identify the impaired waterways requiring intervention and to protect those waterways retaining their exceptional status. This is accomplished by using a probability design for first- to fourth-order streams within each watershed. Each watershed is assessed every five years. Randomly-selected sites are sampled for in-situ water quality (temperature, conductivity, dissolved oxygen, pH, and turbidity) with a multiprobe, macroinvertebrates with a kick-net, and fish with electro-fishing equipment. Water samples are collected for laboratory analysis of nutrients and metals. No trend assessments are performed, but IDEM expects this to be forthcoming once the watershed assessment process matures. (Fore and Yoder 2003; Watershed Assessment Program website <http://in.gov/idem/cleanwater/2338.htm>).

2.2 Reasons for Selecting Overall Design

Wadeable streams and rivers occupy a unique location and purpose on the landscape, influencing their characteristics. Their slopes are steeper, their channels are narrower and shallower, and their riparian areas are less developed than large nonwadeable rivers. Their key distinguishing feature is

their small and dynamic flow volumes. Monitoring of flow-dependent variables in wadeable streams can require a high level of monitoring effort and expense in order to determine statistically-significant water quality trends. Accurately defining the water quality of wadeable streams as a population is a non-trivial task. In addition, park resource managers identified specific local concerns regarding their wadeable streams that favor the implementation of a targeted sampling approach, rather than a randomized sampling approach. For these reasons, we have chosen to focus on monitoring variables that are less dependent on flow and more integrative of overall stream quality (using a combination of physical, chemical, and biological metrics) at targeted index sites of wadeable streams, rather than at the randomly-selected sites of a probabilistic sampling design.

2.3 Spatial Characterization of Monitoring Sites

Each of the selected streams will be monitored at one site. In wadeable streams, a monitoring site entails a selected reach of the stream. For the purposes of this protocol, a monitoring reach is approximately 40 times the mean wetted width of the stream. Eleven equidistant transects are located within the sampling reach (Figure 9). Care should be taken to select a reach for monitoring that is representative of the stream, incorporating all habitats that are typical of the stream in question. A downstream site may begin at the mouth of a selected stream, but in general, locations that are affected by estuarine conditions or lake seiches will be avoided. Areas where normal stream flow is affected by anything creating a hydraulic control such as beaver dams, large bridge abutments, road culverts, low-head dams etc. will also be avoided. Monitoring reaches should not contain tributaries that contribute significant flow to the stream, and the upstream and downstream ends of the reach should be well away from any hydraulic influence that a tributary may have in the reach.

During site establishment, the upper and lower endpoints of a monitoring reach will be identified with GPS (see SOP #4). Once defined, the upstream and downstream boundaries of a monitoring site will remain fixed; each monitoring reach will be established as a permanent study reach and re-sampled every sampling rotation. Re-sampling each location will increase the ability to detect trends by decreasing the sampling error caused by spatial variation. In addition, permanent study reaches provide a greater opportunity to monitor stream channel morphology changes through time.

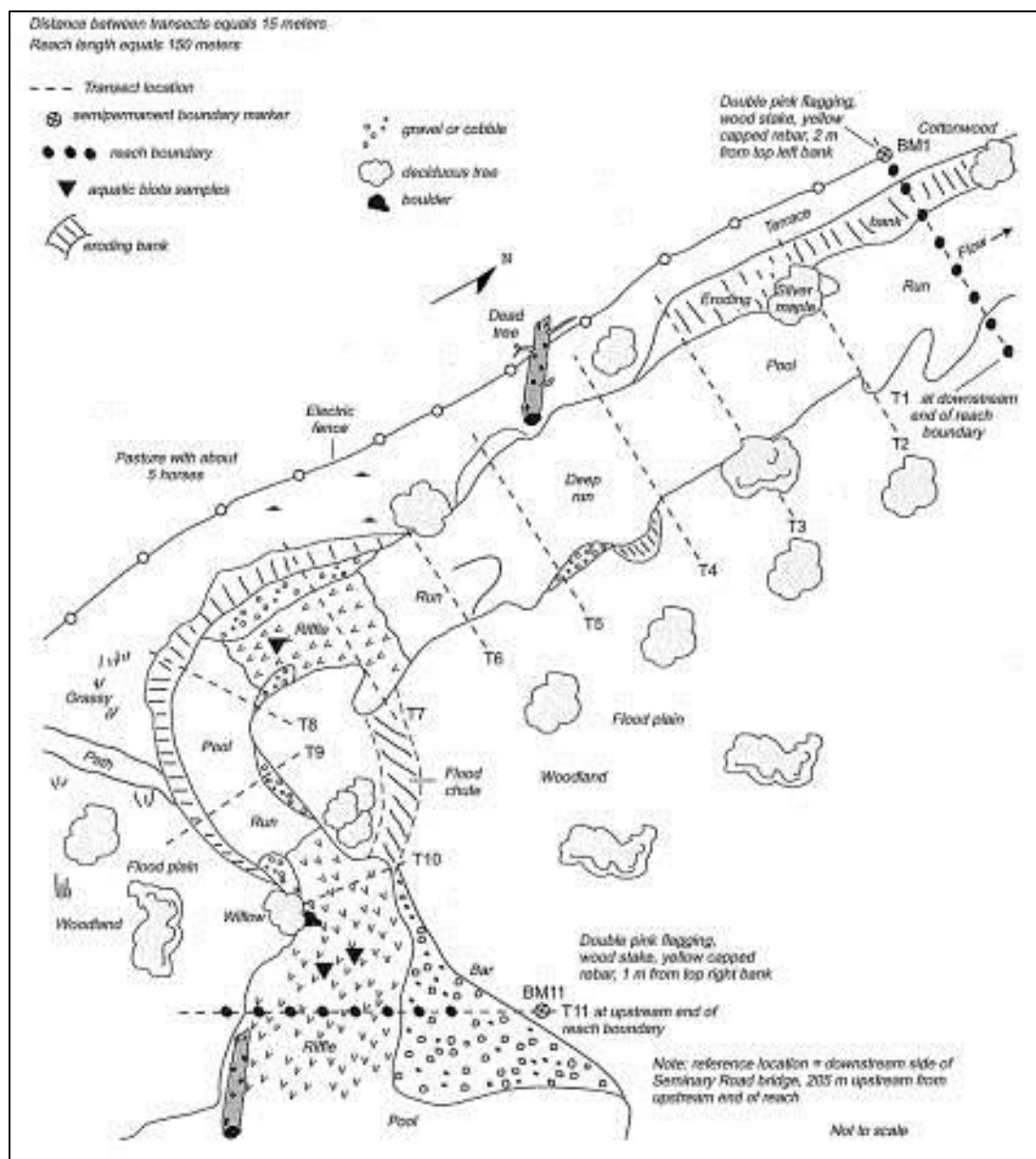


Figure 9. Schematic of sampling reach (from Fitzpatrick et al. 1998).

2.4 Selection of Monitoring Variables

We selected variables for monitoring wadeable streams that will allow us to address the monitoring objectives of this protocol. We have selected a sampling design for wadeable streams that takes an integrative approach by monitoring a range of physical, chemical, and biological metrics of stream ecological health. This design integrates the effects of different stressors over time, providing a broad measure of their aggregate impact under fluctuating environmental conditions. Following a rapid bioassessment approach similar to other agencies (e.g., USEPA 2006, WDNR 2002) we will monitor stream quality through a combination of biotic measurements, namely benthic macroinvertebrates and periphyton; instream habitat assessments; riparian habitat assessments; flow; and water quality

(dissolved oxygen, pH, specific conductance, temperature, and clarity). Some of the advantages of including these variables are outlined below.

2.4.1 Biotic Indicators

The effects of stressors, such as inputs of excess nutrients, invasion and spread of exotic species, and contaminants from atmospheric fallout and surface runoff, on the chemical and biological functions of streams are key issues of concern. By monitoring macroinvertebrates and periphyton we will provide data for a thorough understanding of changes in stream biota over time.

Benthic Macroinvertebrates

Benthic macroinvertebrate communities are good indicators of stream conditions over a period of time, as they integrate the conditions during the course of their lives (Barbour et al. 1999). They are not migratory, making them good indicators of localized conditions, and they are particularly well-suited for assessing site-specific impacts (e.g., upstream-downstream studies). Most have a complex life cycle of approximately one year or more, integrating the effects of short-term (daily and seasonal) environmental variations. Water chemistry samples, on the other hand, represent only a snapshot of conditions present at the time of sampling. While chemistry measurements are still of value, it is the biotic communities that provide information on overall conditions during non-sampling times. Macroinvertebrate species demonstrate differential tolerances of stress and pollution. Therefore, given macroinvertebrate assemblages are representative of known stream conditions. Sensitive life stages of aquatic invertebrates respond rapidly to different environmental stressors, while species assemblages provide robust information on stream integrity (Barbour et al. 1999). Benthic invertebrates are relatively easy and inexpensive to collect and collection has minimal detrimental effect on the population (Barbour et al. 1999). Collection of Benthic Macroinvertebrates, SOP #7, explains the sampling procedures in detail.

Many indices calculated from benthic macroinvertebrate data have been developed as indicators of stressors such as low dissolved oxygen, organic pollution, heavy metals, disruption of stream flow, and high temperatures (Hilsenhoff 1977, 1982, 1987, 1988, 1998; Lillie et al. 2003). Lillie et al. (2003) reviews which macroinvertebrate metric or index to use based on the expected dominant stressors. We will assess and select the metrics and indices that will be the most sensitive to human perturbations within the GLKN area. Potential metrics, including those used by other agencies in the western Great Lakes region are listed in Data Analysis, SOP #12.

Periphyton

Benthic algae, also referred to as periphyton, are primary producers and are an important foundation of many stream food webs. Algae generally have rapid reproduction rates and very short life cycles, making them valuable indicators of short-term impacts. Assessments of periphyton are most effective when used in conjunction with habitat and benthic macroinvertebrate assessments, particularly because of the close relation between periphyton and these elements of stream ecosystems.

We will assess periphyton abundance qualitatively as a component of the instream habitat assessment. We will also collect a composite sample of periphyton from each sampling site and

preserve it for later identification and enumeration of species. See SOP #8, Collection of Periphyton for further details.

2.4.2 Instream Habitat Assessment

The structure and composition of biological communities are dependent upon the quality and quantity of available habitat; hence habitat characterization is particularly important for proper interpretation of bioassessment results (Barbour et al 1999). Habitat characteristics, such as current velocity, substrate composition, degree of embeddedness, channel dimensions, coarse woody material, and amount of algae and macrophytes, affect the distribution and composition of aquatic macroinvertebrate communities (Moulton et al. 2002; Weigel 2003). If habitat conditions degrade (e.g., water quality decreases, embeddedness increases), changes in the benthic macroinvertebrate community are expected to follow (Hilsenhoff 1982; Bowles et al. 2008). Such correlations are the basis of biological indicators (e.g., Sandin and Johnson 2000; Dale and Beyeler 2001; National Research Council 2001; Jørgensen et al. 2005; Southerland et al. 2007).

Our instream habitat assessment is based on the monitoring protocol for stream habitat in Wisconsin (WDNR 2002) and will consist of mapping and measuring habitat features throughout each sampling reach, as well as measuring habitat characteristics in quadrats placed along transects. More specifically, the lengths of habitat features (i.e., runs, riffles, pools, bends, islands, dams, log jams) will be measured, and their distances from the downstream end of the sampling reach will be measured. We will sketch the sampling reach to record channel features and we will record the percent of the reach in different habitat types.

Within each sampling reach, 11 equally-spaced, permanent transects will be established with four equally-spaced quadrats (0.3 m × 0.3 m) along each transect. Within each quadrat, the following measurements or estimates are taken: substrate size and composition, percent embeddedness, depth of fine sediment, canopy cover, percent cover of algae and macrophytes, and stream dimensions (e.g., mean wetted width, bank-full width, depth). Water depth will also be measured at the thalweg, or deepest point in the flowing channel.

Some record of the flow or water level at the time of sampling is critical for the accurate interpretation of other measured sampling values. In addition to measuring flow at the time of sampling, we will deploy continuous depth loggers at each site, and will correlate the depth measurements with nearby gage flow and discharge measurements. USGS gages will be used when available; discharge rating curves will be developed for sites where USGS gages are not present.

2.4.3 Riparian Habitat Assessment

Because conditions in the riparian areas surrounding the streams play such an important role in the function and integrity of the streams, we will monitor aspects of the riparian zone, drawing on the monitoring protocol for stream habitat in Wisconsin (WDNR 2002). The predominant riparian land use will be recorded for both banks at each transect, from the water's edge extending inland 5m. Land use consists of both disturbed (cropland, developed, pasture, barnyard) and undisturbed (forest, shrub/scrub, meadow, wetland) categories. We will measure the amount of contiguous undisturbed

land use within 5m of the water, and we will measure the amount of canopy shading of the stream at each transect using a densiometer. SOP #9 contains details on assessing riparian habitat.

Changes in land use and land cover in the watershed of each stream will be assessed via analysis and interpretation of aerial photos at approximately 6 year intervals (when available), in conjunction with GLKN's land cover/land use monitoring protocol (Kennedy et al. 2010). Local changes to the banks and stream channel observed by the sampling crews on the ground will also be noted.

2.4.4 Water Chemistry

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 (Route and Elias 2005).

During annual sampling, we will measure temperature, pH, specific conductance, and dissolved oxygen with a calibrated multiprobe at both the upstream and downstream ends of each sampling reach at each field visit.

While a traditional synoptic grab sample is easy to obtain, it is a discreet snapshot that does not accurately reflect the dynamic nature of stream systems. Where feasible, we will also deploy continuous temperature and depth loggers, which will facilitate earlier detection of change in these parameters. The Network may also deploy a calibrated multiprobe at a stream site, for the continuous measurement of all core water quality variables, with the goal of continuous monitoring at additional sites where and when feasible, and perhaps rotated through sites. See SOP #6 for details on in situ measurements of water chemistry.

2.5 Sampling Frequency

Streams will be sampled annually, with sampling occurring in the month of July, with final sampling time determined by the project leader and field crews. Refer to SOP #7 for details regarding the scheduling of sampling. The return frequency of this protocol is annual; that is, each sampling reach will be re-visited every year.

2.6 Ability of Chosen Design to Meet Monitoring Objectives

Statistical power analysis (<http://www.dssresearch.com/toolkit/spcalc/power.asp>) was conducted to assess the ability of the historical data to detect a 20% change in annual values of the available monitoring variables, summarized in Table 8. The following three streams with historical monitoring records were chosen for analysis:

- Grand Portage Creek (GRPO), monitored for five years between 1999–2005 by the Grand Portage Band of Chippewa and the National Park Service, at an average frequency of 6 ± 0.4 times per year;

- Little Calumet River (INDU), monitored for ten years between 1990–1999 by the U.S. Geological Survey, at an average frequency of 10 ± 2 times per year; and,
- Washington Creek (ISRO), monitored for thirty-one years between 1965–1996 by the U.S. Geological Survey, at an average frequency of 6 ± 3 times per year.

Table 8. Statistical power (%; $\alpha=0.05$) to detect 20% change, calculated from mean annual values of historically monitored water quality data from Grand Portage Creek, Little Calumet River, and Washington Creek.

Monitoring variable	Grand Portage Creek (n=5)	Little Calumet River (n=10)	Washington Creek (n=31)
Temperature	57*	–	100
pH	100	100	100
Specific conductance	37	100	100
Dissolved oxygen	99	99	100
Transparency tube	22	–	–
Alkalinity	47	100	–
Total phosphorus	11	69	25
Total nitrogen	24	–	–
Nitrate+nitrite-nitrogen	27	55	59
Chlorophyll-a	10	–	–
Chloride	20	98	91
Sulfate	14	–	67
Magnesium	47	–	100
%EPT	100	–	–
%POET	100	–	–
%Tricoptera	79	–	–
%Insects	100	–	–

*Estimated from a single year (NPS sampling in 2000)

– Not measured

EPT = Ephemeroptera-Plecoptera-Trichoptera

POET = Plecoptera-Odonata-Ephemeroptera-Trichoptera

For each monitoring record, variables designated by NPS-WRD as the core suite of water quality variables had good power to detect change; pH and dissolved oxygen were particularly strong. In contrast, the advanced suite of water quality variables demonstrated poor ability to detect change; alkalinity and magnesium were the strongest at a 47% power to detect a 20% change. Finally, some of the biotic metrics with historical data also had strong ability to detect change, and are listed in Table 8. The results of this power analysis of the best available historical data support the justification of not spending our limited budget on monitoring for the advanced suite of water quality variables, but instead to focus on the core suite of water quality variables and biotic measures of stream ecological health.

When the three monitoring records are compared, the increased power of a longer monitoring record becomes apparent. Generally, each variable increases in statistical power to detect change with an increase in the length of monitoring record.

In addition, the three selected monitoring records were analyzed (www.dssresearch.com/toolkit/sscalc/size_a1.asp) for the number of monitoring years that would be required to detect a 20% change at 80% power. The results are summarized in Table 9.

Table 9. Number of years needed to detect 20% change at 80% power ($\alpha = 5\%$), calculated from annual values of historically monitored water quality data from Grand Portage Creek, Little Calumet River, and Washington Creek.

Monitoring variable	Grand Portage Creek (n=5)	Little Calumet River (n=10)	Washington Creek (n=31)
Temperature	11	–	1
pH	2	<1	<1
Specific conductance	2	<1	<1
Dissolved oxygen	2	<1	<1
Transparency tube	47	–	–
Alkalinity	15	<1	–
Total phosphorus	>100	1	20
Total nitrogen	59	–	–
Nitrate+nitrite-nitrogen	36	2	3
Chlorophyll-a	>100	–	–
Chloride	58	<1	2

– Not measured

Table 9 (continued). Number of years needed to detect 20% change at 80% power ($\alpha = 5\%$), calculated from annual values of historically monitored water quality data from Grand Portage Creek, Little Calumet River, and Washington Creek.

Monitoring variable	Grand Portage Creek (n=5)	Little Calumet River (n=10)	Washington Creek (n=31)
Sulfate	>100	–	4
Magnesium	15	–	<1
%EPT	<1	–	–
%POET	<1	–	–
%Trichoptera	1	–	–
%Insects	<1	–	–

– Not measured

EPT = Ephemeroptera-Plecoptera-Trichoptera

POET = Plecoptera-Odonata-Ephemeroptera-Trichoptera

3.0 Field Sampling Methods

This section summarizes the information presented in greater detail in the standard operating procedures (SOPs) #1 (Pre-season Preparation), #4 (Site Establishment) #6 (Water Quality Field Measurements), #7 (Collection of Benthic Macroinvertebrates), #8 (Collection of Periphyton), #9 (Physical Habitat Assessment), #10 (Flow Measurement), and #14 (Post-season Procedures). Refer to the SOPs for more information. In addition, this 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 contained within individual SOPs.

3.1 Establishing Sites and Transects

Prior to the first sampling event, permanent sites must be established. Using aerial photographs along with information from park staff, identify locations that appear to have close to a 1:1:1 ratio of riffles, pools, and runs. Most stream sections will not have this perfect ratio, but areas that are predominantly one type of habitat should be avoided. Locations that are affected by estuarine conditions or lake seiches should be avoided; as should areas where normal stream flow is affected by anything creating a hydraulic control such as beaver dams, large bridge abutments, road culverts, low-head dams, etc. Monitoring reaches should not contain tributaries that contribute significant flow to the stream. Attempt to locate monitoring reaches such that the upstream terminus of the section is well below any hydraulic influence that a tributary may have in the reach. Additionally, if the downstream end of a reach is near a tributary, be sure that any hydraulic effects such as backwater areas or eddies formed from the tributary inflow are not present at the beginning of the monitoring reach.

The length of each monitoring reach will be 40 times the mean stream width (MSW) and will contain 11 equally-spaced permanent transects.

Each newly established site must be evaluated for the availability of flow data. If a USGS stream gage is not located on the selected stream, obtain permission from the park to install a staff gage. Locate the gage near one of the two monitoring sites.

Refer to SOP #4 for details on establishing sites.

3.2 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 10 summarizes which of the SOPs contain key checklists of equipment and supplies for stream 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 10. Checklists of equipment and supplies for monitoring wadeable streams.

Checklist	Location
Safety equipment and supplies	SOP #2
Decontamination equipment and supplies	SOP #5
Field equipment and supplies	SOPs #6 - 10

Review the protocol and all SOPs. Field personnel should be adequately experienced or trained in using field sampling equipment and sample collection methods. Personnel should be familiar with equipment instruction manuals, particularly with regard to calibration and maintenance procedures.

Review and update the field and office binders prior to the field season. Field binders should contain reference information specific to each sampling station, including complete description of and directions to the monitoring site, location coordinates, maps, photos, copies of previous field forms, summaries of sampling and QA/QC procedures, data sheets, and data tables summarizing all previous measurements of field variables. The office binder should contain reference information relevant to general field sampling procedures, including QA/QC reminders, a copy of the protocol narrative and all SOPs, copies of equipment instructions and troubleshooting; extra data sheets, safety data sheets for field supplies that contain hazardous chemicals or materials, and analytical service request and chain of custody forms (if applicable).

The project manager should be sure all required research and collection permits have been obtained. Crew leaders should prepare the field sampling schedule and conduct field reconnaissance prior to the field season to ensure that the sites are accessible. Refer to degree day calendars from previous seasons to get a rough idea of the sampling schedule; keep a running tally of degree days for the current sampling year to determine the final sampling schedule.

3.3 Taking Field Measurements and Collecting Samples

3.3.1 Sequence of Activities

Following is the sequence of activities during any given field day:

1. Prepare sample bottles and labels in advance.
2. Review checklist of field gear.
3. Prepare new data sheets for each monitoring station, printed on waterproof paper. Separate data sheets are needed for a) mapping and measuring habitat features; b) habitat sampling along transects; c) station summary, including water quality; d) flow; e) macroinvertebrate collection; and f) periphyton collection.
4. Conduct daily calibration of appropriate meters and probes.

5. Inspect motorized vehicles/boats at the beginning of every field day, including all safety and directional lights, oil, gasoline, and air pressure levels of tires.
6. Travel to monitoring site. Refer to description of monitoring station location, directions, and photos to verify correct location. Verify coordinates on GPS unit.
7. Measure water quality variables with a multiprobe and transparency with a transparency tube downstream of first transect per SOP #6; record measurements on data sheet.
8. Obtain mean stream width to calculate $40 \times \text{MSW}$ to find sample reach Length, as needed.
9. Moving from downstream to up, conduct physical habitat assessment instream and in the riparian area along transects, Map and measure habitat features as you go. Also as you move upstream, select three riffles or other appropriate habitats for collecting macroinvertebrate and periphyton samples (per SOPs 7 and 8).
10. Collect and preserve macroinvertebrate and periphyton samples, per SOPs #7 and #8, respectively.
11. Measure water quality variables with a multiprobe and transparency with a transparency tube upstream of last transect per SOP #6; record measurements on data sheet.
12. Measure flow along a cross section of the stream (per SOP #10) at an appropriate place within the sampling reach; record measurements on data sheet.
13. Download data from continuous logging devices, replace batteries or logging devices if necessary, and re-deploy.
14. Record stage reading.
15. Verify that all data sheets are completely filled out, and initial them.
16. If sampling more than one monitoring station in a day, go back to step 6, ensuring that equipment has first been decontaminated for invasive species per SOP #5.
17. Return to office or park laboratory.
18. Clean and decontaminate sampling equipment (SOP #5) and perform calibration checks, as detailed in SOP #6.
19. Download field data and check against hard copy field data sheets as soon as feasible.
20. Enter all data into NPSTORET at the end of the season.
21. SOP #9 contains details on mapping and measuring habitat features and conducting physical habitat assessments instream and in the riparian area.

3.3.2 Record Field Information

Waterproof data sheets should be prepared ahead of time, labeled with the project and station IDs. Data sheets are used to record the physical, chemical, and biological sampling data at the time of sample collection. Documentation should include calibration date 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. Examples of conditions to record include the visual appearance of the water, excessive macrophyte or algal growth, presence of fish, unusual odors, dredging, and presence of livestock in the stream. The convention left bank/right bank will be used as follows: left bank is defined as the bank to the left of the observer when facing upstream, and the right bank is to the right of the observer when facing upstream.

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 adjacent to that original entry. All corrections should be initialed and dated.

3.3.3 Measure Water Quality Variables

Electronic sensors must meet the quality control specifications for resolution and accuracy listed in SOP #6. Probes must be submerged and allowed to stabilize prior to recording any readings (see stabilization criteria in SOP #6).

After disturbances from wading have cleared, take field measurements of the core suite of field variables to the side of where you are standing; methods are detailed in SOP #6. Measurements should be made in the center of centroid of flow (see SOP #4), in the center of the water column. Take measurements at the downstream end of the reach prior to conducting other sampling and at the upstream end of the reach after other sampling is complete. Replicate at least 10% of readings or at least once per site per visit, with the replicate taken immediately following the original reading; values should agree within 10% or the stabilization criteria in SOP #6, whichever is larger. Use the transparency tube to measure the clarity of the stream water at both downstream and upstream ends of the reach.

If a continuous data logger has been recording data at the site, download data, change the batteries if necessary, and re-deploy the instrument.

3.3.4 Habitat Assessment

To save time, habitat mapping, measurement, and transect measurements will be conducted concurrently. Starting at the downstream end of the sampling reach, begin measuring upstream to the next habitat feature. As the habitat transects are encountered, the observations at each transect are recorded, then the measurement between habitat features and mapping continues. Specific information about both types of observations is noted below.

Measure and Map Habitat Features

Measuring and mapping habitat features provide a representation of the condition of instream habitats as they are at the time of a given visit. Especially important are habitat features such as bends, pools, runs, riffles, islands, log jams, and dams (built by both beavers and humans). Quantitative measurements of habitat features can be used over several visits to observe changes in

instream habitats over the course of multiple visits. Data regarding riparian habitat are collected both during habitat mapping as well as at each transect. During mapping (section 3.3.4, above), general observations on the riparian corridor and bank conditions are drawn and noted on the map.

Starting at the downstream end of the reach, measure the distance upstream to the beginning of the next habitat feature; record the distance to the nearest 1m. Continue upstream, measuring the distance to each new habitat feature, and record the measurements on the data sheet. After the features of the entire reach have been measured, sketch a map of the site, including both instream and riparian areas, while returning to the downstream end of the reach. The maps will be scanned electronically and kept as part of the site data. Refer to SOP #9 for more details on measuring and mapping habitat features.

Habitat Assessment on Transects

Instream and riparian habitats play a key role in determining the productivity and biodiversity of streams. Therefore, it is important to make observations and specific measurements on habitats to determine if any habitat degradation is impairing ecosystem function. To this end, this stream protocol includes collection of data on instream habitat features as well as riparian habitat and bank conditions. Specific methods for making habitat measurements and observations are detailed in SOP #9.

Eleven equidistant, permanent transects are established within each sampling reach. Along each transect, four equidistant quadrats (0.3 m × 0.3 m) are placed. Within each quadrat the following measurements will be conducted: water depth, water depth plus fine sediment, % embeddedness, % substrate type, % cover by algae, and % cover by macrophytes. In addition to in-stream features, bank erosion (measurements of contiguous bare soil along the stream edge) and riparian land use up to 5m from the streambank are assessed at each transect. Photographs are also taken of both banks at each transect to provide a visual record of bank condition, and riparian land use.

Specific methods are described in SOP #9.

3.3.5 Collect and Preserve Macroinvertebrate Samples

Use D-frame kick net (500 µm mesh, 30.5-cm-wide frame) for all sampling, with a 0.093 m² (30.5 × 30.5cm) PVC frame (approx. 1 ft²) to define the sampling area in riffles, runs, or other flat-bottomed habitat.

If at least three riffles are present in the sampling reach, then all macroinvertebrate samples will be collected from riffles. At most GLKN parks, finding three riffles to sample within each reach will be easily accomplished, especially because permanent reach sites are established at locations with close to a 1:1:1 ratio of riffles, pools, and runs. Three sub-samples will be taken from each individual riffle and composited into a single sample, resulting in a total of three samples collected for each reach.

If a stream reaches with less than three riffles, samples in other habitat types will become necessary, similar to the EPA (Barbour et al. 1999) protocol for multi-habitat sampling. The order of sampling preference is as follows:

1. Three riffles with similar substrate composition

2. Three riffles, regardless of similarity of substrate composition
3. Two riffles and coarse woody debris
4. Two riffles and most abundant other instream habitat type
5. One riffle and coarse woody debris
6. One riffle and two most abundant other instream habitat types
7. Coarse woody debris (if enough exists for 20 kick/jab samples)
8. Coarse woody debris and other instream habitat by proportion of occurrence

If after mapping the sampling reach you have determined that three riffles with similar substrate composition do not occur, estimate the proportion of the reach in each other habitat type (e.g., snags, sand, vegetated banks) and record on the data sheet. Following the prioritization above, determine how many kicks or jabs to do with the kick net in each habitat type.

Do a total of 20 kicks or jabs if no riffles exist. Consider each riffle sub-sample equivalent to two kicks or jabs in other habitats. Therefore, in a reach with one riffle, three sub-samples would be collected in the riffle which would count as 6 kicks or jabs in other habitats. Therefore, 14 kicks or jabs would be taken in other habitats throughout the rest of the reach to complete sampling. If two riffles are present and sampled, then that would mean that eight net samples would have to be collected in the other habitats. For further details on macroinvertebrate sampling in all habitats and sample compositing, please see SOP #7.

3.3.6 Collect Periphyton Samples

Three random periphyton subsamples will be collected from each of three riffles. The subsamples from each individual riffle will be composited into a single sample for each riffle, resulting in three samples for each reach. Ideally, all periphyton subsamples will be scraped from cobble substrates found within the same three riffles where macroinvertebrate samples were collected. If fewer than three riffles are present, then the remaining samples will be collected from large, coarse woody debris.

Measure and record the total volume of the composited sample, then pour the sample back into the composite bottle. Mix well, then remove a 10 mL aliquot from the sample, and filter through a GF/C filter for chlorophyll-*a* analysis. Repeat with 5 mL aliquots until the filter turns a greenish color, being sure to record the number of mL filtered. From the remaining sample in the composite container, draw a 125 mL sample into a vial (Bahls 1993). Add the recommended amount of Lugol's (IKI) solution, "M3" fixative, buffered 4% formalin, 2% glutaraldehyde, or other preservative (APHA 1995).

Each sample container will be labeled with both internal and external labels according to SOP #8; the type of preservative used will be included on the label.

3.3.7 Record Stage Reading/ Measure Flow

At the time of sampling, measure the stream height relative to a staff gage or permanent structure and record the reading on the flow data form. Measure the current velocity at a suitable location within the reach or nearby, if no suitable location occurs within the reach, as detailed in SOP #10. Record the information on the flow form. If a continuous depth logger has been recording data at the site, download the data, check the batteries, and re-deploy the instrument. Obtain flow information from co-located or nearby USGS gaging station, if available. If no gauging station is present, then collect flow measurements as outlined in SOP #10.

3.3.8 Departure from Monitoring Site

Before leaving the monitoring site, review all data sheets and sample labels for legibility, accuracy, and completeness. All flags must be explained in the comments section. Make sure the header information is complete on all forms. Record the departure time on the data sheet(s). After reviewing each form, initial the upper right corner of the form.

Return all equipment and supplies to the field vehicle and pack them for transport. Keep equipment and supplies organized so they can easily be inventoried using checklists. Properly dispose of any waste material.

3.4 Post-Collection Procedures

Inspect and clean all equipment that has come in contact with stream water according to SOP #5, Decontamination of Equipment to Remove Exotic Species. This effort limits the spread of nuisance species and prevents possible cross-contamination of samples. Keep equipment and supplies properly organized and labeled so they can easily be inventoried using the checklists.

Prior to sending any samples to a contract laboratory, notify the lab that samples are ready to be shipped and ensure that someone will be available to receive the samples. 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 (ASR) form and/or the Chain-of-Custody (COC) form provided by the lab. Pack samples carefully in the shipping container according to laboratory protocols, to prevent bottle breakage, shipping container leakage, and sample degradation.

Enter data into appropriate spreadsheets and databases as soon as possible to minimize error. Refer to the instrument manufacturer's instruction manual for details on downloading data from dataloggers. Update the data to include the latest field measurements. Field, laboratory, and biological data should be uploaded into the appropriate database at least annually, per SOP #11.

3.5 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 data sonde according to specific instructions in the manufacturer's manual. Store calibration standards and electrolyte solutions in a temperature-controlled environment. Clean all nets and waders according to SOP #5, and store appropriately such that materials do not crease or otherwise degrade and become compromised.

3.6 Quality Assurance and Quality Control

The objective of quality assurance/quality control (QA/QC) is to ensure that the data generated by a project are meaningful, representative, complete, precise, accurate, comparable, and scientifically defensible (O’Ney 2005). It is a broad management concept requiring the complete integration of field and laboratory procedures for sample collection and analysis. The QA/QC procedures that pertain to sample collection and processing are focused on ensuring that any given field or laboratory measurement accurately represents the resource at the time the sample was collected. This includes activities that range from instrument calibration, to sampling water quality from the streamflow midpoint, to collecting biological samples from the appropriate habitats, to specification of field methods. Table 11 summarizes the QA/QC procedures pertaining to sampling methods that will be followed by this protocol.

Table 11. Summary of QA/QC procedures pertaining to sampling methods.

Procedure	Description/Reason
Instrument calibration logs	Each instrument must have a logbook. All calibration results and maintenance activities must be recorded in the log. Calibration schedule must be observed, using fresh calibration standards.
Office binder	This binder will contain a complete copy of the protocol and all SOPs, Safety Data Sheets, analytical service request and chain of custody forms.
Field binder	This binder will contain directions to sampling sites, GPS coordinates of sampling locations, previous field data to compare with new measurements, summaries of sampling and QA/QC procedures, discharge rating curve to verify new stage readings.
Data sheets	Photocopies of data sheets are placed in field binders. Original data sheets must be kept on file at a secure location indefinitely.
Field instrument methods	Consistent measurement methods and detection limits are required. Refer to SOPs #6 and #10 for water quality and flow sampling methods, respectively, and manufacturer’s instruction manuals for troubleshooting.
Multiprobe performance	Document sensitivity of multiprobes through an estimation of the limits of detection, known as alternative measurement sensitivity (AMS). Estimate systematic error/bias of the multiprobe through the use of reference solutions.
Field replicates	Replicate multiprobe field measurements at the rate of approx.10%, or at least once per site. Calculate the relative percent difference to document precision of the multiprobe.
Continuous data loggers	Identify and correct for drift on all continuous monitoring data loggers.
Sample preservation	Preserve macroinvertebrate samples in 95% ethanol; ensure bottle lids are secure

Table 11 (continued). Summary of QA/QC procedures pertaining to sampling methods.

Procedure	Description/Reason
Chain-of-custody	A chain of custody includes not only the form, but all references to the sample in any form, and documents the possession of the samples from the time they were collected until the sample results are received.
Macroinvertebrate and periphyton identification	Requires experience and expertise. Samples will be sent to a contract lab for identification. Approximately 10% of the samples will be re-counted or re-sampled, according to SOPs # 7 and #8.

One important aspect in the accuracy and precision of a water quality monitoring program is the correct selection of field instruments and their subsequent calibration and maintenance schedule. Typical field sensor performance specifications and the ideal calibration frequency and minimum acceptance criteria for these probes can be found in SOP #6. The reality of logistical constraints at back country sites may preclude calibration and checks of calibration at the ideal frequency. Maintain calibration logs for multi-parameter sondes to 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.

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 or import all required metadata for NPSTORET and Aquatic Informatics' Aquarius database; the data and metadata will ultimately be moved to the EPA STORET database or for Aquarius maintained by NPS-WRD staff in Ft. Collins, Colorado.

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/constan.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 EPA data and table structures in, to facilitate easier movement of I&M networks' water quality data into EPA Water Quality Exchange (WQX) framework. We will use NPSTORET as the primary data entry tool and data transfer mechanism to WRD. In addition, GLKN uses Aquatic Informatics' Aquarius system for storage and visualization of continuously monitored water quality data from automated loggers (i.e., water temperature data from continuous temperature loggers).

The 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 must be used. The Network will continue to improve tools for automating analysis and visualization of the information contained in the NPSTORET and Aquarius datasets.

4.3 Data Entry, Verification, Certification, 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 file. The second class of data is the results of testing performed by contract analytical laboratories. The last class of water quality data is digital data that have been collected by multiprobe sondes and other field data loggers. GLKN will develop formatting routines to be applied to the digital files prior to importation of data into NPSTORET or Aquarius.

Data verification starts with the QA/QC steps that are outlined in the SOPs associated with this protocol. If data being imported into NPSTORET do not pass a QA/QC test, NPSTORET prompts the user to make corrections and re-import 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 imported into NPSTORET or Aquarius 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. Once returned to GLKN by WRD, and after appropriate documentation is completed, the dataset is officially considered certified. Only qualified users who have been trained and given edit permissions are allowed to edit data in NPSTORET or Aquarius. 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 #11 and are summarized below in Table 12.

Table 12. 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.
Data entry	At least 10% of electronic data (e.g. multiprobe, GPS) entries should be spot checked on a random basis for errors. If errors are found, another 10% are spot checked. 100% of handwritten data from field data sheets are checked upon data entry.
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 certification	Data certification demonstrates that data are complete for the period of record; 2) they have undergone and passed the quality assurance checks; and 3) that they are appropriately documented and in a condition for archiving, posting and distribution as appropriate.
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 Data Analysis Procedures

After all data QA/QC procedures have been completed each year, brief characterizations of the data from each NPS unit that was sampled and from the Network as a whole will be performed. The methods of characterization will depend on the types of data that are collected. The data collected on wadeable streams includes continuously-logged data (i.e., temperature and depth), synoptic data that is both categorical (e.g., substrate type) and continuous (e.g., core water quality), and biological community assemblage data (i.e., macroinvertebrates and periphyton), each of which requires a different method of analysis.

Analysis of both the status and trends of wadeable stream data will be conducted. Status refers to a static description of a stream at a point in time. Trend refers to whether directional change is occurring over a period of time. Common analytical methods for assessing status and determining whether a trend is occurring are summarized below. In addition, if long-term trends indicate changes may be occurring, the methods for identifying the statistically-significant minimum detectable change are included below. See SOP #12 for additional details on data analytical methods.

4.6.1 Status

1. Temporal plots – simple graphical assessments of stream data, including comparison to regulatory standards.
2. Normal data methods – applicable to normally-distributed data, includes common summary statistics of median, mean, and standard deviation.
3. Non-normal data transformations – reduces skew and enables the application of normal data methods to slightly non-normal distributions.
4. Nonparametric methods – alternatives for identifying correlations or the central tendency and dispersion of the data.
5. Differences between upstream and downstream sites – comparisons that enable the identification of land use impacts or landscape dynamics.
6. O/E methods – the ratio between the observed (O) data value and the best available information for the expected (E) data value, which is derived either from local historical (prior to degradation) data sets or from regional (least impacted reference sites) data sets.
7. Multimetric vs. multivariate methods – similar to O/E methods, status is determined by comparison to unimpacted conditions. Both methods demonstrate strengths (see discussion and table in SOP #12), therefore both methods will be used on wadeable streams data.
8. Multimetric index methods – indices that calculate a composite score from multiple biological metrics have been developed for both periphyton and macroinvertebrates.
9. Multivariate ordination methods – community assemblage data are analyzed in multidimensional space to identify habitat and water quality variables that account for the largest portion of the variance in the data.

4.6.2 Trends

1. Mann-Kendall methods – applicable to synoptic data collected annually.
2. Seasonal Kendall methods – applicable to continuously-logged data.
3. Regional Kendall methods – the Mann-Kendall test is applied to several locations to determine whether the same trend is evident across those locations.

4.6.3 Detectable Change

1. Power analysis methods for parametric data.
2. Two-sample tests for nonparametric data.

4.7 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.

As mentioned above, routine data summaries will be conducted annually for streams and parks that are sampled within that year. The summaries will be compiled from data that has been uploaded to the EPA's STORET database or the Aquarius database by NPS-WRD. Hard copy or web-based summary reports will be produced periodically, after the data is certified, with the primary audience being the parks. More comprehensive reports, with analyses of trends, will occur after several seasons of sampling.

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.

4.8 Report Format

Both annual summaries and reports that include detailed analyses on trends should adhere to Servicewide I&M reporting guidelines for Natural Resource Data Summary reports (for annual summaries) and Natural Resource Reports (for detailed analysis reports). Refer to the Natural Resource Publications Management website for the most up-to-date guidelines and formats (<http://www.nature.nps.gov/publications/NRPM/index.cfm>).

Tables are appropriate for displaying simple data summaries, for example, mean annual values of water quality variables collected at one park. Figures are useful for comparisons or when examining

relationships between variables, for example, concentration trends across years. Reports should include tables and figures appropriate for the data and for the intended audience.

5.0 Personnel Requirements and Training

5.1 Roles and Responsibilities

The GLKN staffing plan includes an aquatic ecologist as project manager, two additional aquatic ecologists as project assistants, and four seasonal biological technician positions. We anticipate that the personnel in these positions will train park staff in sampling procedures and assist with site establishment. The primary field sampling will be conducted by park staff with assistance from GLKN staff when possible.

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), contractors, 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 supervise the implementation of standard procedures for field data collection and data handling.
- Coordinate logistics with park staff.

Develop a quality assurance/quality control standard operating procedure for the project:

- According to NPS guidelines (Irwin 2004, 2006). Supervise staff training and conduct quality assurance checks of field sampling techniques at least every other year with each field crew.
- Contract with a laboratory for identification and enumeration of biological samples. Ensure products meet program needs (e.g., QA/QC procedures, 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 project assistants and the data manager in the following capacities:

- Complete project documentation in appropriate databases (describing who, what, where, when, why, and how of a project).

- Develop data verification and validation measures for quality assurance.
- Ensure staff members 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 Field Personnel (Field Crew Member/Leader)

Field personnel may consist of park staff, seasonal technicians, and GLKN staff. 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 ensuring logistical requirements will be met. Responsibilities for both crew member and crew leader include the following:

- Complete all training for field sampling and sample handling.
- Complete all phases of field season preparation.
- Collect data and samples according to developed protocols.
- Pack and ship biological samples to contractor.
- Maintain accurate field and office notes.
- Ensure that all quality assurance and quality control procedures are implemented.
- Maintain and calibrate equipment according to protocols and manufacturers' directions.
- Communicate progress and accomplishments with the project manager during (if necessary) and after sampling; 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 project manager for archival on a regular basis.
- Represent the Network in a professional manner; assist in maintaining positive communication among the Network, park staff, and the public.

5.1.3 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, hydrology, chemistry, or other related science. Field experience is mandatory. Prior leadership experience and good decision-making skills are highly desirable, as is experience working on water.

Crew members should have a background in biology or other related science, although an undergraduate degree is not required. Prior field experience, including that with water, is highly desirable.

All crew members must be physically fit, able to work long hours in inclement weather, and able to lift and carry heavy loads.

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 project
- Calibration, operation, and maintenance of all field and laboratory meters and probes used in the project
- Methods for macroinvertebrate and periphyton sample collection
- Methods for cleaning equipment
- Methods for handling and preserving samples

- Methods for measuring streamflow
- Completion of field data forms, sample labels, chain-of-custody forms, analytical service request forms
- Data entry/import into appropriate databases
- 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 for monitoring of wadeable streams will be approximately one day per site, once a rating curve has been developed. Water quality measurements, collection of macroinvertebrates and periphyton, and physical habitat assessments will be conducted once annually at each site.

If flow is to be measured by NPS staff, development of a rating curve for each sampling site will require multiple visits in order to take measurements in a variety of flow conditions. We expect to develop the rating curves over several years at sites without an established stream gage nearby. By installing continuous depth loggers at the outset of the project, we will be able to back-calculate depth relative to discharge once the rating curve is completed. For sites where an existing USGS gauging station is already installed, there are likely already rating curves for these sites.

6.2 Facility and Equipment Needs

The field crew will need a facility with a sink and counter-top space where they can calibrate and clean instruments and process samples. They will also need secure space for storing field equipment. Currently, all five parks have the necessary facilities.

6.3 Startup Costs and Budget Considerations

6.3.1 Equipment and Initial Start-up Costs

Each sampling crew will need its own equipment for routine monitoring because sampling will occur at five parks each year, widely separated in distance. Some of the parks already have some of the necessary sampling gear and equipment, and the Network has begun to acquire some as funds permit.

Start-up costs are expected to be approximately \$16,065 (Table 13), excluding equipment already available; annual estimated costs of equipment and supplies are approximately \$3,000. The vast majority of the start-up costs are for multiprobes for continuous monitoring. These sondes are not essential to begin monitoring, and will be purchased over time as the budget allows. Many of the items listed are also used in monitoring programs for inland lakes and large rivers.

6.3.2 Staff Salaries

No additional personnel will be hired to accomplish the wadeable streams monitoring. Because sampling at each site is expected to take one day or less, the demands on existing staff will be minimal. Park staff will conduct the sampling with assistance and QA/QC oversight by GLKN staff. GLKN staff will conduct training and help park staff establish sites. Salary for GLKN staff (Project Manager and Assistants, Data Manager) will be covered by I&M and WRD funding.

6.3.3 Vehicle and Travel

Travel expenses will vary by year. Initially, when sites are being established and staff members are being trained, costs will be higher. Once routine monitoring is underway, travel will be limited to QA/QC visits to each park every other year. Travel to each park will coincide with other water quality monitoring related visits whenever possible. Typical costs of travel to each park from GLKN

headquarters, with two nights lodging (in the case of ISRO, one night of hotel in Houghton and three nights on the island) and per diem, varies from \$340 to \$566 (Table 14).

Table 13. Expected start-up costs of wadeable streams monitoring program, including one-time purchases and routine expenses.

Item	# Available	# Needed	Cost Each (\$)	Total Cost (\$)
multi-probe sonde for synoptic sampling	5	0	7000	0
multi-probe sonde for continuous monitoring*	2	1	5000	5,000
GPS unit and software	5	0	300	0
laptop computer	5	0	2500	0
digital camera	5	0	400	0
temperature loggers	17	0	125	0
depth loggers*	2	14	450	6300
kick net*	3	5	200	1000
communications shuttle, software for loggers*	2	3	215	645
flow meter*	4	5	2500	2500
transparency tube*	3	2	55	110
measuring tapes*	2	3	50	150
densimeters*	2	3	100	300
NIST traceable thermometer*	3	2	30	60
Total of one-time purchases (still needed)	—	—	—	\$16,065
miscellaneous field equipment (boots, buckets, PFDs, backpacks)	—	—	1000	1000
miscellaneous lab equipment (forceps, basins)	—	—	500	500
other consumables (buffers, ethanol, bottles, labels)	—	—	1000	1000
shipping invertebrate samples for identification	—	—	500	500
Total annual/periodic expenses	—	—	—	\$3000

* indicates one-time start-up expenses; remaining expenses are expected to reoccur periodically or annually.

Table 14. Estimated costs for round-trip travel from GLKN headquarters to each park.

Costs	GRPO	INDU	ISRO	PIRO	SLBE
Mileage for GSA vehicle @ 0.29/mile	129	285	96	141	285
Lodging	166	166	83	166	166
Per diem	115	115	161	115	115
Total costs	\$410	\$566	\$340	\$422	\$566

6.3.4 Cost of Biota Identification

The cost of identifying and enumerating macroinvertebrate samples will vary depending on factors such as level of taxonomic effort (resolution) and subsample size. Assuming 300 to 400 macroinvertebrates comprise a single sample, we estimate a per sample analysis cost of \$500 based on personal communication with contractors. The total annual cost, assuming 14 sites (no samples need be collected at GRPO) sampled once annually, is estimated at \$7,000.

The estimated per sample cost of identification and enumeration of periphyton will be similar. Therefore, the annual cost for this work, assuming 16 sites, will be approximately \$8000.

6.3.5 Total Estimated Annual Costs

Estimates for starting a long-term stream monitoring program and the annual implementation costs (Table 15), are relatively low because much of the equipment and supplies have already been purchased and are being used for other aquatic monitoring (inland lakes, Elias et al. 2015; large rivers, Magdalene et al. 2016; diatoms, Ramstack et al. 2008). As in the other aquatic protocols, the Network will pursue opportunities for cost-sharing with parks, both for equipment and personnel.

Table 15. Estimated total costs for monitoring streams at five park units of the Great Lakes Network.

Item	Amount
travel (assume one trip/yr/park)	\$2064
sample ID	\$15,000
one-time equipment	\$16,065
annual supplies	\$3,000
Total	\$36,129

6.4 Procedures for Revising and Archiving Previous Versions of the Protocol

As our stream 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 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 #16). 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.

Literature Cited

- Albert, D. 1992. A survey of lakes, streams, and wetlands of the Sleeping Bear Dunes National Lakeshore. Final report to Sleeping Bear Dunes National Lakeshore. Michigan Natural Features Inventory, Lansing, Michigan.
- Albright, J., M. Martin, and B. Jackson. 2002. Preliminary hydrologic and hydraulic characterization of instream flows of the Crystal River, Sleeping Bear Dunes National Lakeshore, Leelanau County, Michigan. Final report to Sleeping Bear Dunes National Lakeshore. National Park Service, Water Resources Division, Ft. Collins, Colorado.
- Allan, J. D. 1995. Stream ecology: Structure and function of running waters. Kluwer Academic Publishers, Dordrecht, the Netherlands.
- Arihood, L. 1975. Water-quality assessment of the Indiana Dunes National Lakeshore, 1973–74. Water-Resources Investigations Report 14-75, U.S. Geological Survey.
- Barbour, M. T., J. Gerritsen, B. D. Snyder, and J. B. Stribling. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: Periphyton, benthic macroinvertebrates and fish (2nd edition). EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C. Available at: www.epa.gov/owow/monitoring/rbp/download.html.
- Bowden, R. D. 1981. Benthic macroinvertebrates and chemistry of three streams on Isle Royale National Park, Michigan. Thesis. Michigan Technological University, Houghton, Michigan.
- Bowles, D. E., J. A. Luraas, L. W. Morrison, H. R. Dodd, M. H. Williams, G. A. Rowell, M. D. DeBacker, J. A. Hinsey, F. D. Usrey, and J. L. Haack. 2007. Protocol for monitoring aquatic invertebrates at Ozark National Scenic Riverways, Missouri, and Buffalo National River, Arkansas. Natural Resource Report NPS/HTLN/NRR—2007/009. National Park Service, Fort Collins, Colorado.
- Bowles, D. E., M. H. Williams, H. R. Dodd, L. W. Morrison, J. A. Hinsey, C. E. Ciak, G. A. Rowell, M. D. DeBacker, and J. L. Haack. 2008. Monitoring protocol for aquatic invertebrates of small streams in the Heartland Inventory & Monitoring Network Natural Resource Report NPS/HTLN/NRR—2008/042. National Park Service, Fort Collins, Colorado.
- Boyle, T., and N. Hoefs. 1993. Water resources inventory of Sleeping Bear Dunes National Lakeshore. Final report to Sleeping Bear Dunes National Lakeshore, National Park Service. Colorado State University, Ft. Collins, Colorado.
- Boyle, T. and A. Richmond. 1997. Report on the ecological monitoring of two streams in Grand Portage National Monument. U.S. Geological Survey, Biological Resources Division, Ft. Collins, Colorado.
- Boyle, T., R. Waltermire, and G. Gustina. 1999. Risk analysis of the aquatic resources in Pictured Rocks National Lakeshore: An ecologically-based inventory and estimation of the effects of land

- use practices. U.S. Geological Survey, Midcontinent Ecological Science Center, Ft. Collins, Colorado.
- Canale, R. 2002. Annual report for the year 2001 – Consent agreement concerning operation of the Platte River hatchery. Sleeping Bear Dunes National Lakeshore.
- Carlisle, D. M. 2002. Draft ecological assessment of an Isle Royale stream following a fuel spill. Unpublished report to Isle Royale National Park, National Park Service, Midwest Regional Office, Omaha, Nebraska.
- Crane, T., B. M. Lafrancois, J. Glase, M. Romanski, M. Schneider, and D. Vana-Miller. 2006. Water resources management for Isle Royale National Park Michigan. National Park Service, Water Resources Division, Ft. Collins, Colorado.
- Curry, K. 1973. A base line survey of the Crystal River drainage basin, Leelanau County, Michigan. Final report to Glen Lake Association Water Quality Committee. Central Michigan University, Mt. Pleasant, Michigan.
- Curry, K. 1977. Species structure of midge (Diptera: Chironomidae) communities in Crystal River drainage basin, Leelanau County, Michigan, 1972. Thesis. Central Michigan University, Mt. Pleasant, Michigan.
- Dale, V. H., and S. C. Beyeler. 2001. Challenges in the development and use of ecological indicators. *Ecological Indicators* 1:3–10.
- Daues, T. V. 1991. Furbearer activity relative to habitat in Pictured Rocks National Lakeshore. Thesis. University of Wisconsin, Stevens Point, Wisconsin.
- Environmental Resources Management. 1985. Platte River corridor study. Final report to the National Park Service, Midwest Region, Contract No. CX6000-3-0059, Environmental Resources Management – North Central, Frankfort, Michigan.
- Elias, J. E., R. Axler, E. Ruzycki, and D. VanderMeulen. 2015. Water quality monitoring protocol for inland lakes: Great Lakes Inventory and Monitoring Network, version 1.1. Natural Resource Report NPS/GLKN/NRR—2015/1027. National Park Service, Fort Collins, Colorado.
- Fessel, B. 2007. Inventory and evaluation of inland fisheries at Sleeping Bear Dunes National Lakeshore. National Park Service, Great Lakes Inventory and Monitoring Network Report GLKN/2007/03.
- Fitzpatrick, F. A., I. R. Waite, P. J. D'Arconte, M. R. Meador, M. A. Maupin, and M. E. Gurtz. 1998. Revised methods for characterizing stream habitat in the National Water-Quality Assessment Program. United States Geological Survey Water Resources Investigation Report 98-4052. Available at: <http://pubs.usgs.gov/wri/wri984052/>.

- Flower, H., and B. Walker. 1999a. A biological survey of the Crystal River, Leelanau County, September 1998. Staff Report MI/DEQ/SWQ-99/083, Michigan Department of Environmental Quality, Surface Water Quality Division, Cadillac, Michigan.
- Flower, H., and B. Walker. 1999b. A biological survey of the Platte River system, Benzie County, August 1998. Staff Report MI/DEQ/SWZ-99/083, Michigan Department of Environmental Quality, Surface Water Quality Division, Cadillac, Michigan.
- Fore, L., and C. O. Yoder. 2003. The design of a biological community trend monitoring program for Michigan wadeable streams. Michigan Department of Environmental Quality, Surface Water Quality Division, Great Lakes and Environmental Assessment Section. Report MI/DEQ/WD-03/086.
- Genet, J., and J. Chirhart. 2004. Development of a macroinvertebrate index of biological integrity (MIBI) for rivers and streams of the Upper Mississippi River Basin. Minnesota Pollution Control Agency Biological Monitoring Program, St Paul, Minnesota. Available at: www.pca.state.mn.us/publications/reports/biomonitoring-mibi-uppermiss.pdf.
- Gerovac, P., and R. Whitman. 1995. Fishes of the Pictured Rocks National Lakeshore. Research report to Pictured Rocks National Lakeshore. U.S. Department of the Interior, National Biological Service, Lake Michigan Biological Station, Porter, Indiana.
- Goldstein, R. 2000. Grand Portage Reservation environmental monitoring program. Open-File Report 00-69. U.S. Geological Survey, Mounds View, Minnesota.
- Grand Portage National Monument. 2000. Grand Portage National Monument Level 1 water quality survey, 2000. Produced by the Division of Resource Management, Grand Portage National Monument, Grand Marais, Minnesota.
- Handy, A., and F. Twenter. 1985. Water resources of Pictured Rocks National Lakeshore, Michigan. Water-Resources Investigations Report 85-4013, U.S. Geological Survey, Lansing, Michigan.
- Hardy, M. 1983. Chemical and biological quality of streams at the Indiana Dunes National Lakeshore, Indiana, 1978–80. Water-Resources Investigations 83-4208, U.S. Geological Survey, Indianapolis, Indiana.
- Hazlett, B. 1989. The aquatic vegetation and flora of the Sleeping Bear Dunes National Lakeshore, Benzie and Leelanau Counties, Michigan. Report to the National Park Service, Contract CX6000-4-0072, Department of Biology, University of Michigan, Ann Arbor, Michigan.
- Heiman, M., and M. Woller. 2003. Glen Lake/Crystal River watershed management plan. Final report to Glen Lake Association, by Leelanau Conservancy with cooperation from Glen Lake Association and Friends of the Crystal River.
- Heuschele, A. 2000. What are the biomonitoring needs for the streams in Sleeping Bear National Lakeshore? A review of two macroinvertebrate surveys and suggestions for rapid bioassessment

- for the flowing waters of SLBE. Report to Sleeping Bear Dunes National Lakeshore. Normandale Community College, Bloomington, Minnesota.
- Hill, A. R. 2000. Stream chemistry and riparian zones. *In* J. B. Jones, and P. J. Mulholland. Streams and ground waters. Academic Press. London, United Kingdom.
- Hilsenhoff, W. L. 1977. Use of arthropods to evaluate water quality of streams. Technical Bulletin 100. Wisconsin Department of Natural Resources, Madison, Wisconsin. Available at: <http://digital.library.wisc.edu/1711.dl/EcoNatRes.DNRBull100>.
- Hilsenhoff, W. L. 1982. Using a biotic index to evaluate water quality in streams. Technical Bulletin 132. Wisconsin Department of Natural Resources, Madison, Wisconsin.
- Hilsenhoff, W. L. 1987. An improved biotic index of organic stream pollution. *Great Lakes Entomologist* 20:31–39.
- Hilsenhoff, W. L. 1988. Seasonal correction factors for the biotic index. *Great Lakes Entomologist* 21:9–13.
- Hilsenhoff, W. L. 1998. A modification of the biotic index of organic stream pollution to remedy problems and permit its use throughout the year. *Great Lakes Entomologist* 31:1–12.
- Hoefs, N. 1993. The Platte River study: Assessment of ecological integrity of stream invertebrate community. Final report to Sleeping Bear Dunes National Lakeshore. Colorado State University, Ft. Collins, Colorado.
- Holmes, R. M. 2000. The importance of ground water to stream ecosystem function. *In* J. B. Jones, and P. J. Mulholland. Streams and ground waters. Academic Press. London, United Kingdom.
- Hynes, H. B. N. 2001. *The Ecology of Running Waters*. The Blackburn Press. Caldwell, New Jersey.
- Irwin, R. 2004. Vital signs long-term aquatic monitoring projects, part B: Planning process steps. Issues to consider and then to document in a detailed study plan that includes a quality assurance project plan (QAPP) and monitoring protocols (standard operating procedures). National Park Service, Ft. Collins, Colorado.
- Irwin, R. 2006. Part B lite (Just the Basics). QA/QC review checklist for aquatic vital sign monitoring protocols and SOPs. National Park Service, Ft. Collins, Colorado.
- Jørgensen, S. E., R. Costanza, and F-L. Xu. 2005. *Handbook of Ecological Indicators for Assessment of Ecosystem Health*. CRC Press. Boca Raton, Florida.
- Kelly, T., and B. Price. 1979. *Fishes of the Sleeping Bear Dunes National Lakeshore*. Final report to the National Park Service and Eastern National Park and Monument Association.
- Kennedy, R., A. Kirschbaum, U. Gafvert, P. Nelson, Z. Yang, W. Cohen, E. Pfaff, and B. Gholson. 2010. Landsat-based monitoring of landscape dynamics in the national parks of the Great Lakes

- Inventory and Monitoring Network (version 1.0). Natural Resource Report NPS/GLKN/NRR—2010/221. National Park Service, Fort Collins, Colorado.
- Kraft, G. J., D. J. Mechenich, C. Mechenich, J. E. Cook, and S. M. Seiler. 2010. Assessment of natural resource conditions: Isle Royale National Park. Natural Resource Report NPS/NRPC/WRD/NRR—2010/237. National Park Service, Fort Collins, Colorado.
- Kraft, G. J., D. J. Mechenich, C. Mechenich, M. D. Waterhouse, J. McNelly, J. Dimick, and J. Cook. 2014. Natural resource conditions assessment: Grand Portage National Monument. Natural Resources Report NPS/GRPO/NRR—2014/783. National Park Service, Fort Collins, Colorado.
- Kusnierz, P. C. 2008. The age structure, length, condition, and movement of resident and coaster brook trout (*Salvelinus fontinalis*) in Pictured Rocks National Lakeshore. Thesis. Northern Michigan University, Marquette, Michigan.
- Kusnierz, P. C., S. P. Stimmell, and J. B. K. Leonard. 2009. Movement and growth indicators in resident and adfluvial coaster brook trout (*Salvelinus fontinalis*) in Hurricane River, Lake Superior, USA. *Journal of Great Lakes Research* 35:385–391.
- Lafrancois, B. M., and J. Glase. 2005. Aquatic studies in national parks of the upper Great Lakes States: Past efforts and future directions. Water Resources Division Technical Report, NPS/NRWRD/NRTR—2005/334. National Park Service, Denver, Colorado.
- Lafrancois, B. M., M. Watkins, and R. Maki. 2009. Water quality conditions and patterns on the Grand Portage Reservation and Grand Portage National Monument, Minnesota: Implications for nutrient criteria development and future monitoring. Natural Resource Technical Report NPS/GLKN/NRTR—2009/223. National Park Service, Ft. Collins, Colorado.
- Lillie, R. A., S. W. Szczytko, and M. A. Miller. 2003. Macroinvertebrate data interpretation guidance manual. Wisconsin Department of Natural Resources, Madison, Wisconsin. Available at: https://www.google.com/url?q=http://dnr.wi.gov/water/wsSWIMSDocument.ashx%3FdocumentSeqNo%3D17895392&sa=U&ved=0ahUKEwi9o8T7_sLWAhUICcAKHYTkC384ChAWCAQwAA&client=internal-uds-cse&usg=AFQjCNG3_FZ1jm7h4dTeG7rPTN-WyJorHg.
- Limnetics, Inc. 1970. A preliminary survey of the environmental quality of the Pictured Rocks National Lakeshore and Recreational Area, Alger County, Michigan. Limnetics, Inc., Environmental Research and Engineering, Milwaukee, Wisconsin.
- Linton, M. 1987. Analysis of habitat for invertebrates in stream systems of Sleeping Bear Dunes National Lakeshore. Short report/manuscript for Sleeping Bear Dunes National Lakeshore.
- Loope, L. 2004. Aquatic monitoring plan for Pictured Rocks National Lakeshore. National Park Service, Munising, Michigan.

- Loope, W., and M. Holman. 1991. An assessment of stream bed and stream bank characteristics within Pictured Rocks National Lakeshore. Pictured Rocks National Lakeshore Resource Report PIRO091-1. National Park Service, Munising, Michigan.
- Loope, W., and S. Scott. 1987. A reintroduction of grayling (*Thymallus arcticus*) to the inland waters of Picture Rocks National Lakeshore, Michigan. U.S. Department of the Interior, National Park Service and Michigan Department of Natural Resources report to Pictured Rocks National Lakeshore.
- Mac, M. J., P. A. Opler, C. E. Puckett Haecker, and P. D. Doran. 1998. Status and trends of the nation's biological resources (2 vols.). U.S. Department of the Interior, U.S. Geological Survey, Reston, Virginia. Available at: <http://www.nwrc.usgs.gov/sandt/index.html>.
- Magdalene S., D. R. Engstrom, J. Elias, D. VanderMeulen, and R. Damstra. 2016. Large rivers water quality monitoring protocol: Great Lakes Inventory and Monitoring Network (version 1.1). Natural Resource Report NPS/GLKN/NRR—2016/1262. National Park Service, Fort Collins, Colorado.
- Martin, M. 2008. Evaluation of Grand Portage Creek channel morphology and instability. Memorandum to Superintendent, Grand Portage National Monument (GRPO). L54 (2380). January 10, 2008.
- Mast, M. A., and J. Turk. 1999. Environmental characteristics and water quality of Hydrologic Benchmark Network stations in the west-central United States, 1963–95. U.S. Geological Survey Circular 1173-B.
- MiDEQ. (Michigan Department of Environmental Quality). 2008. Procedure #51: Qualitative biological and habitat survey protocols for Wadeable streams and rivers. Michigan Department of Environmental Quality, Surface Water Quality Division, Great Lakes and Environmental Assessment Section. Water Bureau Policy and Procedures WB-SWAS-051. Available at: www.michigan.gov/documents/deq/wb-sw-as-procedure51_280711_7.pdf.
- MiDEQ (Michigan Department of Environmental Quality). 1999. A biological survey of the Platte River system, Benzie County, August 3–5, 1998. Michigan Department of Environmental Quality, Surface Water Quality Division.
- Mechenich, C., G. J. Kraft, S. W. Szczytko, and D. J. Mechenich. 2006. Assessment of coastal water resources and watershed conditions at Pictured Rocks National Lakeshore. Natural Resource Technical Report NPS/NRWRD/NRTR—2006/361. National Park Service, Fort Collins, Colorado.
- Mechenich, C., D. J. Mechenich, S. W. Szczytko, J. E. Cook, and G. J. Kraft. 2009. Assessment of natural resource conditions: Sleeping Bear Dunes National Lakeshore. Natural Resource Report NPS/NRPC/WRD/NRR—2009/097. National Park Service, Fort Collins, Colorado.

- Meldrum, J. 1987. Bacterial water sampling program, 1984–85. Isle Royale National Park Resource Management Report 87-1. National Park Service, Houghton, Michigan.
- Michigan Department of Conservation. 1953–1980. Stream fish collection datasheets. Fish Division, D-4. Newberry, Michigan.
- Moulton, S. R., J. G. Kennen, R. M. Goldstein, and J. A. Hambrook. 2002. Revised protocols for sampling algal, invertebrate, and fish communities as part of the National Water-Quality Assessment Program. United States Geological Survey Open File Report 02-150. Available at: <http://pubs.usgs.gov/of/2002/ofr-02-150/>.
- Mulholland, P. J., and D. L. DeAngelis. 2000. Surface-subsurface exchange and nutrient spiraling. *In* J. B. Jones, and P. J. Mulholland. Streams and ground waters. Academic Press. London, United Kingdom.
- Murphy, P. 2001. Water quality and aquatic ecology at Sleeping Bear Dunes National Lakeshore: 2000–2001 year-end review. Sleeping Bear Dunes National Lakeshore.
- Naiman, R. J., H. Décamps, and M. E. McClain. 2005. Riparia: Ecology, Conservation, and Management of Streamside Communities. Elsevier Academic Press. San Diego, California.
- National Research Council. 2001. Ecological Indicators for the Nation. National Academy Press. Washington, D.C.
- Newman, L. 1993. Progress report on coaster brook trout restoration at Grand Portage Reservation. Report to Grand Portage Reservation Natural Resources Program Director.
- Newman, L. 2001. Stream assessment of Pictured Rocks National Lakeshore, 1988. U.S. Fish and Wildlife Service report to Pictured Rocks National Lakeshore. Ashland Fishery Resources Office, Ashland, Wisconsin.
- Newman, L., and J. Johnson. 1996. Development of a reintroduced, anadromous brook trout population at Grand Portage, Minnesota, 1991–1996. U.S. Department of the Interior, Fish and Wildlife Service report, Ashland Fishery Resources Office, Ashland, Wisconsin.
- Nichols, S., E. Crawford, J. Amberg, G. Kennedy, G. Black, and J. Allen. 2001. Status of freshwater unionid populations at Pictured Rocks National Lakeshore, 1999–2000. Final report to National Park Service, Pictured Rocks National Lakeshore from the U.S. Geological Survey, Great Lakes Science Center, Ann Arbor, Michigan.
- Niemela, S. L., D. Christopherson, J. Genet, and J. Chirhart. 2004. Condition of rivers and streams in the St. Croix River basin of Minnesota. Minnesota Pollution Control Agency, St. Paul, Minnesota.

- Niemela, S, D. Christopherson, J. Genet, J. Chirhart, and M. Feist. 2005. A comprehensive assessment of rivers and streams in the St. Croix River basin using a random site-selection process. Environmental Bulletin No. 6. Minnesota Pollution Control Agency, St Paul, Minnesota.
- NPS (National Park Service). 2003. Draft general management plan and wilderness study environmental impact statement, Pictured Rocks National Lakeshore, Alger County, Michigan. United States Department of the Interior, National Park Service.
- NPS (National Park Service). 2001. Resource management plan: Grand Portage National Monument. United States Department of the Interior, National Park Service.
- NPS (National Park Service). 1999. Baseline water quality data inventory and analysis: Grand Portage National Monument. Technical Report NPS/NRWRD/NRTR—98/195. National Park Service, Water Resources Division, Ft. Collins, Colorado.
- NPS (National Park Service). 1997. Baseline water quality data inventory and analysis: Sleeping Bear Dunes National Lakeshore. Technical Report NPS/NRWRD/NRTR—97/106. National Park Service, Water Resources Division, Ft. Collins, Colorado.
- NPS (National Park Service). 1995a. Baseline water quality data inventory and analysis, Isle Royale National Park. Technical Report NPS/NRWRD/NRTR—05/41. National Park Service, Water Resources Division, Ft. Collins, Colorado.
- NPS (National Park Service). 1995b. Baseline water quality data inventory and analysis: Pictured Rocks National Lakeshore. Technical Report NPS/NRWRD/NRTR—95/57. National Park Service, Water Resources Division, Ft. Collins, Colorado.
- NPS (National Park Service). 1994. Baseline water quality data inventory and analysis: Indiana Dunes National Lakeshore. Technical Report NPS/NRWRD/NRTR—94/31. National Park Service, Water Resources Division, Ft. Collins, Colorado.
- NPS (National Park Service). 1991. Little Calumet River corridor plan. Indiana Dunes National Lakeshore. United States Department of the Interior, National Park Service, Denver Service Center.
- Pictured Rocks National Lakeshore and Michigan Department of Natural Resources. 1995. Fisheries management plan for Pictured Rocks National Lakeshore. Pictured Rocks National Lakeshore, Munising, Michigan.
- Ruhl, J. 1994. Water resources of the Grand Portage Indian Reservation, northeastern Minnesota. Water-Resources Investigations Report 94-4199. U.S. Geological Survey, Mounds View, Minnesota.
- Sandin, L., and R. K. Johnson. 2000. The statistical power of selected indicator metrics using macroinvertebrates for assessing acidification and eutrophication of running waters. *Hydrobiologia* 422/423:233–243.

- Simon, T., and P. Stewart. 1999. Structure and function of fish communities in the southern Lake Michigan Basin with emphasis on restoration of native fish communities. *Natural Areas Journal* 19:142–154.
- Simon, T., P. Moy, and D. Barnes. 1998. New distribution records for exotic and non-indigenous fish species in the Lake Michigan drainage, Indiana. *Proceedings of the Indiana Academy of Science* 107:61–70.
- Slade, J. 1995. October 1994 Isle Royale brook trout assessment. Memorandum from the U.S. Fish and Wildlife Service to National Park Service.
- Slade, J., and B. Olson. 1994. Results of 1993 survey of the species composition and relative abundance of fish in Isle Royale tributaries to Lake Superior. Memorandum to Natural Resources Specialist, Isle Royale National Park. U.S. Department of the Interior, Fish and Wildlife Service, Ashland Fishery Resources Office, Ashland, Wisconsin.
- Southerland, M. T., G. M. Rogers, M. J. Kline, R. P. Morgan, D. M. Boward, P. F. Kazyak, R. J. Klauda, and S. A. Stranko. 2007. Improving biological indicators to better assess the condition of streams. *Ecological Indicators* 7:751–767.
- Spacie, A. 1988. Fishes of the Indiana Dunes – Species distributions and habitats. Department of Forestry and Natural Resources, Purdue University. Report to Indiana Dunes National Lakeshore.
- Starkey, E. N, L. K. Garrett, T. J. Rodhouse, G. H. Dicus, and R. K. Steinhorst. 2008. Upper Columbia Basin Network integrated water quality monitoring protocol: Narrative version 1.0. Natural Resource Report NPS/UCBN/NRR—2008/026. National Park Service, Fort Collins, Colorado. Available at: <http://science.nature.nps.gov/im/units/ucbn/reports/>.
- Stimmell, S. P. 2006. Migratory activity of two strains of brook trout (*Salvelinus fontinalis*) in Pictured Rocks National Lakeshore characterized using stationary RFID systems. Thesis. Northern Michigan University. Marquette, Michigan.
- Stockwell, J., and J. Gannon. 1975. Water quality studies in the Sleeping Bear Dunes National Lakeshore region—The lower Platte River system, Michigan. Technical Report No. 2, University of Michigan Biological Station, Pellston, Michigan.
- Stockwell, J. E., and J. E. Gannon. 1975. Water quality studies in the Sleeping Bear Dunes National Lakeshore region, the lower Platte River system, and Florence Lake, Michigan. Pages 1–67, part II E in M. W. Paddock, editor. Natural history surveys of Pictured Rocks National Lakeshore and Sleeping Bear Dunes National Lakeshore. University of Michigan Biological Station, Douglas Lake, Pellston, and Ann Arbor, Michigan.
- Stottlemeyer, R. 1982. The neutralization of acid precipitation in watershed ecosystems of the Upper Peninsula of Michigan. Pages 261–274 in F. D'Itri, editor. Acid precipitation: Effects on ecological systems. Ann Arbor Science Publishers, Ann Arbor, Michigan.

- Taube, C. 1974. A descriptive and historical account of the Platte River, its surrounding area, and its salmonid fishes. Fisheries Research Report No. 1809. Michigan Department of Natural Resources, East Lansing, Michigan.
- Toczydlowski, D. G., T. Abramson, R. S. Burdett, T. Beecher-Rocker, R. DePuydt, M. A. Mitchell, J. Rice, and J. Stave. 1978. Aquatic baseline on Isle Royale, Michigan. Isle Royale National Park, National Park Service, U.S. Department of the Interior.
- Turner, M. G., and S. R. Carpenter. 2005. Sidebar 1.2. Challenges for riparian science. Page 16 in R. Naiman, H. Décamps, and M. E. McClain. 2005. *Riparia: Ecology, conservation, and management of streamside communities*. Elsevier Academic Press. San Diego, California.
- USEPA (United States Environmental Protection Agency). 2006. Wadeable streams assessment: A collaborative survey of the nation's streams. EPA/841/B06/002. Available at: www.epa.gov/owow/streamsurvey/pdf/WSA_Assessment_May2007.pdf.
- University of Michigan Biological Station. 1975. Natural history surveys of Pictured Rocks National Lakeshore and Sleeping Bear Dunes National Lakeshore. University of Michigan Biological Station, Douglas Lake, Pellston, and Ann Arbor, Michigan.
- Vana-Miller, D. L. 2002. Water resources management plan for Sleeping Bear Dunes National Lakeshore, Michigan. National Park Service, Water Resources Division. Ft. Collins, Colorado.
- Walker, B. 1998. Evaluation of alternative phosphorus loading scenarios for the Platte River watershed and hatchery. Final Report for Michigan Department of Natural Resources. Concord, Massachusetts.
- WDNR (Wisconsin Department of Natural Resources). 2002. Guidelines for evaluating habitat of wadeable streams. Wisconsin Department of Natural Resources, Bureau of Fisheries Management. Available at: https://infotrek.er.usgs.gov/doc/wdnr_biology/FieldSampling/Wadable/QuantitativeStreamHabitatProtocols.pdf.
- WDNR (Wisconsin Department of Natural Resources), 2006. Guidelines for collecting macroinvertebrate samples from wadeable streams. Wisconsin Department of Natural Resources, Bureau of Fisheries Management. Available at: https://infotrek.er.usgs.gov/doc/wdnr_biology/archives/Macroinvproto.pdf.
- WDNR (Wisconsin Department of Natural Resources). 2015. Wisconsin's draft water monitoring strategy 2015–2020. Available at: http://dnr.wi.gov/topic/SurfaceWater/monitoring/strategy/final_monitoring_V6.pdf.
- Weigel, B. M. 2003. Development of stream macroinvertebrate models that predict watershed and local stressors in Wisconsin. *Journal of North American Benthological Society* 22:123–142.

- White, D. 1987. Analysis of the limnology of four streams (Platte River, Crystal River, Shalda Creek, Otter Creek) in the Sleeping Bear Dunes National Seashore based on the macroinvertebrate fauna. Final report to Sleeping Bear Dunes National Lakeshore by the Benthos Laboratory (GLRC), University of Michigan, Ann Arbor, Michigan.
- Whitman, R., L. Last, and P. Gerovac. 1994. Limnological characteristics of selected lakes and streams of Sleeping Bear Dunes National Lakeshore inspected during summer 1994. Final report, National Park Service Contracts DI6620-R041 and DI6620-R040. National Biological Service, Lake Michigan Ecological Station, Porter, Indiana.
- Wilde, F. D. 2008. Guidelines for field-measured water quality properties. Chapter A6 in United States Geological Survey Techniques of Water Resources Investigations Book 9 National Field Manual. Available at: <http://water.usgs.gov/owq/FieldManual/Chapter6/Chapter6.0v2.pdf>.
- Williamson, C. E., W. Dodds, T. K. Kratz, and M. A. Palmer. 2008. Lakes and streams as sentinels of environmental change in terrestrial and atmospheric processes. *Frontiers in Ecology and the Environment* 6(5):247–254.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 920/141375, December 2017

National Park Service
U.S. Department of the Interior



Natural Resource Stewardship and Science

Natural Resource Stewardship and Science

1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov