



Water Quality Monitoring Protocol for Wadeable Streams and Rivers in the Northern Great Plains Network

Narrative Version 1.0

Natural Resource Report NPS/NGPN/NRR—2014/868



ON THE COVER

Little Missouri River, Theodore Roosevelt National Park North Unit
Photograph courtesy of M. Bynum, Northern Great Plains Network

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Natural Resource Report NPS/NGPN/NRR—2014/868

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October 2014

U.S. Department of the Interior

National Park Service

Natural Resource Stewardship and Science

Fort Collins, Colorado

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Please cite this publication as:

Wilson, M. H., B. L. Rowe, R. A. Gitzen, S. K. Wilson, and K. J. Paintner-Green. 2014. Water quality monitoring protocol for wadeable streams and rivers in the Northern Great Plains Network: Narrative version 1.0. Natural Resources Report NPS/NGPN/NRR—2014/868. National Park Service, Fort Collins, Colorado.

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 standard operating procedures (SOPs) will promptly notify the General Ecologist and/or the Northern Great Plains Network (NGPN) Data Manager regarding recommended and required changes. The General Ecologist will review and incorporate all changes, complete the revision history log, and change the date and version number on the title page and in the footer of the document file. For complete instructions, please refer to SOP 8 “Protocol Revision.”

Previous Version #	Revision Date	Revised By	Changes Made	Reasons for Change	New Version #
1.0 Draft	Month Year	NGPN	Revision following peer review		1.0
Add rows as needed for each change or set of changes tied to an updated version number					

1. Version numbers increase incrementally by hundredths (e.g., version 1.01, version 1.02,...etc.) for minor changes. Major revisions should be designated with the next whole number (e.g., version 2.0, 3.0, 4.0 ...). Record the previous version number, date of revision, author of the revision, identify paragraphs and pages where changes are made, and the reason for making the changes along with the new version number.
2. Notify the NGPN Data Manager of any changes to the Protocol Narrative or SOPs.
3. Post new versions on the internet and forward copies to all individuals with a previous version of the Protocol Narrative or SOPs.

As recommended by Oakley et al. (2003), this protocol consists of a narrative and a set of SOPs that detail the steps to collect, manage, and disseminate the NGPN water quality data. SOPs are within an accompanying document and include:

SOP 1: Preseason Preparations

SOP 2: Selection of Water Quality Monitoring Sites

SOP 3: Measurement of Water Quality Parameters at Sites

SOP 4: Measurement of Streamflow at Sites

SOP 5: Data Management

SOP 6: Data Analysis and Reporting

SOP 7: Postseason Procedures

SOP 8: Protocol Revision

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Executive Summary

Preserving the national parks unimpaired for the enjoyment of future generations is a fundamental purpose of the National Park Service (NPS). To address growing concerns regarding the overall physical, chemical, and biological elements and processes of park ecosystems, the NPS implemented science-based management through “Vital Signs” monitoring in 270 national parks (NPS 2007). The Northern Great Plains Network (NGPN) is among the 32 National Park Service Networks participating in this monitoring effort. The NGPN will develop protocols over the next several years to determine the overall health or condition of resources within 13 parks located in Nebraska, North Dakota, South Dakota, and Wyoming.

The NGPN identified water resources as a Vital Sign to monitor because water quality and quantity are important aspects of ecological processes that operate across multiple temporal and spatial scales. In the semi-arid region of the Northern Great Plains, surface-water resources within the NGPN are ecologically important. The 13 parks within the NGPN are diverse and vary greatly in size, visitation, and water resources. For example, the measured surface area of the Badlands National Park is about 243,000 acres, which represents nearly one-half of the combined acreage of all 13 NGPN park units; however, water resources within the park are scarce and the majority of streams are intermittent. The Badlands National Park annually hosts nearly 860,000 visitors. Mount Rushmore National Memorial also has limited water resources but hosts nearly 3 million visitors per year within its 1,278 acres. The Missouri National Recreational River contains the greatest portion of waterbodies within the NGPN, consisting of 139 rivers and streams within an areal extent of about 69,000 acres. Although water resources and acreage of the NGPN parks are varied, unifying factors among the parks include the relatively low population density within the Great Plains area and the strong emphasis on agrarian land use throughout the region.

To address the diverse water quality concerns, NGPN received input from park staff and conducted pilot studies in 2009 and 2010. These factors, in combination with the NGPN budget allocations, resulted in development of the NGPN’s water quality monitoring protocol. This protocol will provide a context to aid park resource managers in their day-to-day decisions and allow the assessment of the status (current conditions) and trends (directional changes across time) of streams/rivers within selected NGPN parks. Data collected from integrating water resource monitoring, in combination with the inventory of additional Vital Signs, can be used to assess resources and to aid in sound managerial decisions by the NGPN parks.

As recommended by Oakley et al. (2003), this protocol provides a narrative and the rationale for selection of streams and rivers within the NGPN that will be measured for water quality, including dissolved oxygen, pH, specific conductivity, and temperature. Standard operating procedures (SOPs) that detail the steps to collect, manage, and disseminate the NGPN water quality data are in an accompanying document. The sampling design documented in this protocol may be updated as monitoring information is collected and interpreted, and as refinement of methodologies develop through time. In addition, evaluation of data and refinement of the program may necessitate potential

changes of program objectives. Changes to the NGPN water quality protocols and SOPs will be carefully documented in a revision history log.

Acknowledgments

Funding for this project was provided through the National Park Service Natural Resource Challenge and the Service Wide Inventory & Monitoring Program. We want to thank Joyce Williamson, hydrologist from the U.S. Geological Survey South Dakota Water Science Center, for her contributions. We also thank Scot Caesar, John Wrede, Jane Swedlund, and Lee Margadant from Northern Great Plains Network for their field assistance with the pilot projects needed to complete this plan. Gina Ottem and Bob Manasek from Scotts Bluff National Monument; Bill Whitworth and Laurie Richardson from Theodore Roosevelt National Park; Pamela Sprenkle and Linda Ramos from Niobrara National Scenic River; Dean Reasoner from Fort Laramie National Historic Site; Mark Biel from Devils Tower National Monument; and Marc Ohms from Wind Cave National Park helped with field work. Finally, we thank Janet Carter and Keith Lucy from the U.S. Geological Survey and Dean Tucker and Pete Penoyer from the National Park Service for reviewing this document. Janice Faaborg provided technical editing of this document.

Abbreviations and Acronyms

>	greater than
$\geq$	greater than or equal to
<	less than
$\leq$	less than or equal to
#	number
$\mu\text{g/L}$	micrograms per liter
$\mu\text{S/cm}$	microsiemens per centimeter
ADAPS	Automated Data Processing System (U.S. Geological Survey)
CCC	Civilian Conservation Corps
CSV	comma-separated value
CWA	Clean Water Act
$^{\circ}\text{C}$	degrees Celsius
DO	dissolved oxygen
<i>E. coli</i>	<i>Escherichia coli</i>
ft^3/s	cubic feet per second
FY	fiscal year
HIF	Hydrologic Instrumentation Facility (U.S. Geological Survey)
I&M	Inventory & Monitoring
km^2	square kilometers
mi^2	square miles
mg/L	milligram per liter
mL	milliliters
ND	North Dakota
NE	Nebraska
NGPN	Northern Great Plains Network

NHS	National Historic Site
NM	National Monument
NMEM	National Memorial
NP	National Park
NPS	National Park Service
NPSTORET	National Park STOrage and RETrieval
NRR	National Recreational River
NSR	National Scenic River
NWIS	National Water Information System (U.S. Geological Survey)
SD	South Dakota
SOP	standard operating procedure
TMDL	total maximum daily load
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WRD	Water Resources Division of NPS
WSC	Water Science Center (U.S. Geological Survey)
WY	Wyoming

Park Four Letter Alpha Codes

AGFO	Agate Fossil Beds NM
BADL	Badlands NP
DETO	Devils Tower NM
FOLA	Fort Laramie NM
FOUS	Fort Union Trading Post NHS
JECA	Jewel Cave NM

KNRI	Knife River Indian Villages NHS
MNRR	Missouri NRR
MORU	Mount Rushmore NMEM
NIOB	Niobrara NSR
SCBL	Scotts Bluff NM
THRO	Theodore Roosevelt NP
WICA	Wind Cave NP

Background

The Northern Great Plains Network (NGPN) includes 13 National Park Service (NPS) units in Nebraska, North Dakota, South Dakota, and eastern Wyoming (Figure 1). These 13 NPS units include four national monuments (NMs), three national historic sites (NHSs), three national parks (NPs), a national recreational river (NRR), a national scenic river (NSR), and a national memorial (NMEM).

The NGPN parks encompass an extremely large diversity of surface-water resources. Lotic waters include permanent rivers, streams, and springs; ephemeral streams and springs; and constructed irrigation ditches. Lentic environments include lakes, ponds, and impoundments (Table 1). In addition, the two cave parks have a diversity of underground water resources ranging from small drip sites to cave lakes.

Nearly all surface-water features interact with groundwater. In a natural state, groundwater arrives at a balance with surface water, discharging and recharging depending on hydrologic conditions. However, the withdrawal of water resources associated with anthropogenic use within Nebraska, North Dakota, South Dakota, and Wyoming may result in withdrawal of water from aquifers faster than the aquifers are being recharged (Luckey et al. 1988; Johnson and Bouzaher 1995). For example, Luckey et al. (1988) reported groundwater declines of 50–100 feet in the vicinity of NGPN park units in western Nebraska. Overoptimistic perceptions about water abundance can lead to excessive use and may have wide-ranging effects on local and regional hydrology and ecology.

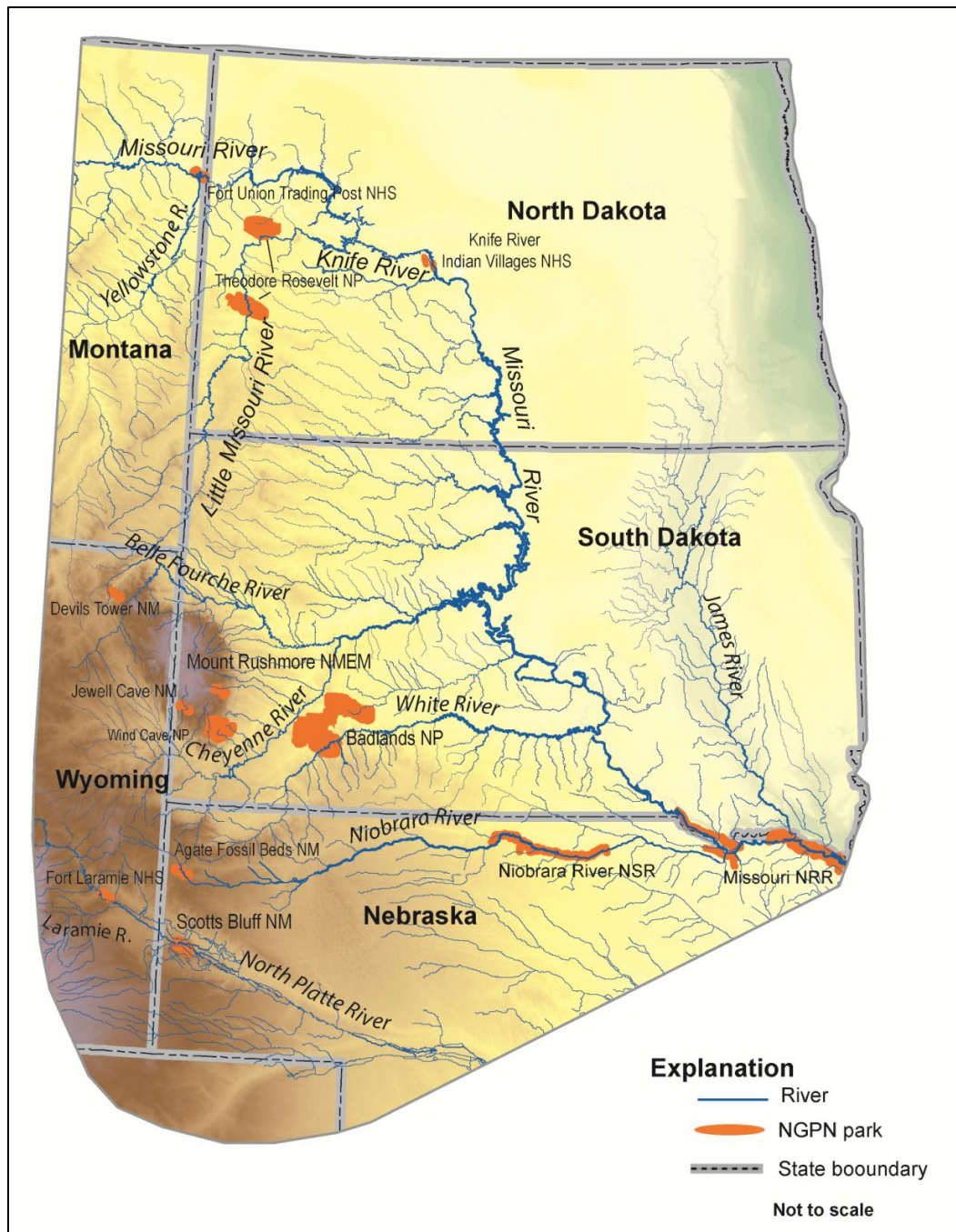


Figure 1. Major rivers and tributaries in Northern Great Plains Network (NGPN) park units.

Table 1. Waterbodies in the Northern Great Plains Network (NGPN) park units. Statistics are based on 1:24,000-scale National Hydrography Dataset (NPS 2012). Values are miles of streams, rivers, and canals, and acres of lakes, reservoirs, impoundments, and swamp/marsh. □

Park	Perennial Stream/ Rivers in Park	Perennial Streams/Rivers Adjacent to Park	Intermittent Streams	Canals	Perennial, Intermittent, and Ephemeral Lakes/ Reservoirs ¹	Swamp/M arsh	Number of Springs
Agate Fossil Beds NM (AGFO)	13.3	0	10.2	1.3	0	33.1	0
Badlands NP (BADL)	3.8	0	1,307.1	0	106.5	0	0
Devils Tower NM (DETO)	0.9	1.5	1.1	0	0	0	3
Fort Laramie NHS (FOLA)	2.9	1.1	0.7	1.0	0	1.1	0
Fort Union Trading Post NHS (FOUS)	0	1.4	0.1	0	0	1.6	0
Jewel Cave NM (JECA)	0	0	5.9	0	0	0	2
Knife R. Indian Villages NHS (KNRI)	4.6	1.8	1.1	0	0	0	0
Missouri NRR (MNRR)	142.9	0	45.1	0.5	725.9	453.1	0
Mount Rushmore NMEM (MORU)	<0.1	0	2.5	0	0	0	0
Niobrara NSR (NIOB)	104.6	0	64.2	0	25.2	35.9	4
Scotts Bluff NM (SCBL)	0	1.5	14.7	2.9	1.7	0	0
Theodore Roosevelt NP (THRO)	21.2	7.2	269.3	0	2.6	0	0
Wind Cave NP (WICA)	15.3	0	127.3	0	3.8	0	3
Total	309.5	14.5	1,849.3	5.7	865.7	524.8	12

¹Lakes and reservoirs in BADL, THRO, and WICA consist of small impoundments created for livestock or wildlife.

Factors Affecting Water Resources in NGPN Parks

To help summarize and consider factors affecting the NGPN's diverse aquatic systems, a conceptual model (Figure 2) was developed to summarize the major factors that structure and change the aquatic ecosystems of the NGPN (Gitzen et al. 2010). External drivers are forces that have large-scale effects on the aquatic ecosystems of the Northern Great Plains. These forces include natural drivers such as geomorphology, watershed processes, and climate regime (Poff et al. 2002), and anthropogenic effects from human economy and sociology (Figure 2).

The varied geology of the Northern Great Plains has been an external force shaping the riverine systems and affecting the quantity and quality of water resources within the NGPN park units. In the western and central parts of the NGPN, former geologic events relating to the Laramide orogeny of the Rocky Mountains and Black Hills are in stark contrast to the extreme glaciation that covered the eastern part of the NGPN (Conner and Harrison 2003). Sediments from the mountain-building events were eroded by fluvial systems that created dramatic topographic features within Badlands NP (BADL) and Theodore Roosevelt NP (THRO), and to a lesser extent within Agate Fossil Beds NM (AGFO) and Scotts Bluff NM (SCBL). Mount Rushmore NM (MORU) is located in the rugged 1.7 billion-year-old granite of the Black Hills. At lower elevations, sedimentary formations encircle the granitic core of the Black Hills, and dissolution of limestone resulted in cavernous systems within Jewel Cave NM (JECA) and Wind Cave NP (WICA). Devils Tower (DETO) was formed by magma that was injected between sedimentary rock layers about 50 million years ago and cooled underground (NPS 2005). The Niobrara NSR (NIOB) is located in the Nebraska Sandhills, a region that was once a vast sand dune complex composed of fine-grained aeolian (windblown) loess produced from past periods of glaciation (Darton 1903).

The Northern Great Plains has a continental climate with dramatic weather extremes that are considered normal events for the region (Wilken 1988). Winter precipitation accumulates as snow pack in much of the Great Plains and supplies the area with useable water. Stream hydrographs are dominated by peaks from snowmelt runoff in spring with much lower base flows occurring in late summer, fall, and winter. The Great Plains experiences multiyear droughts in cycles that generally range from 10 to 20 years (Clark et al. 2002).

Regional and Within Park Stressors

Stressors of park aquatic systems can result in physical, chemical, or biological effects that are either anthropogenic or natural but occurring at an excessive or deficient level (Barrett et al. 1976). Both anthropogenic and naturally occurring stressors to the aquatic systems potentially can create changes in water quality and water supply, affect biodiversity of biota, and alter riparian areas and wetlands (Longo and Yoskowitz 2002). These stressors may be regional factors external to the park boundaries or originating within the NGPN parks themselves and can substantially affect the ecological components, patterns, and processes in natural aquatic systems (Figure 2).

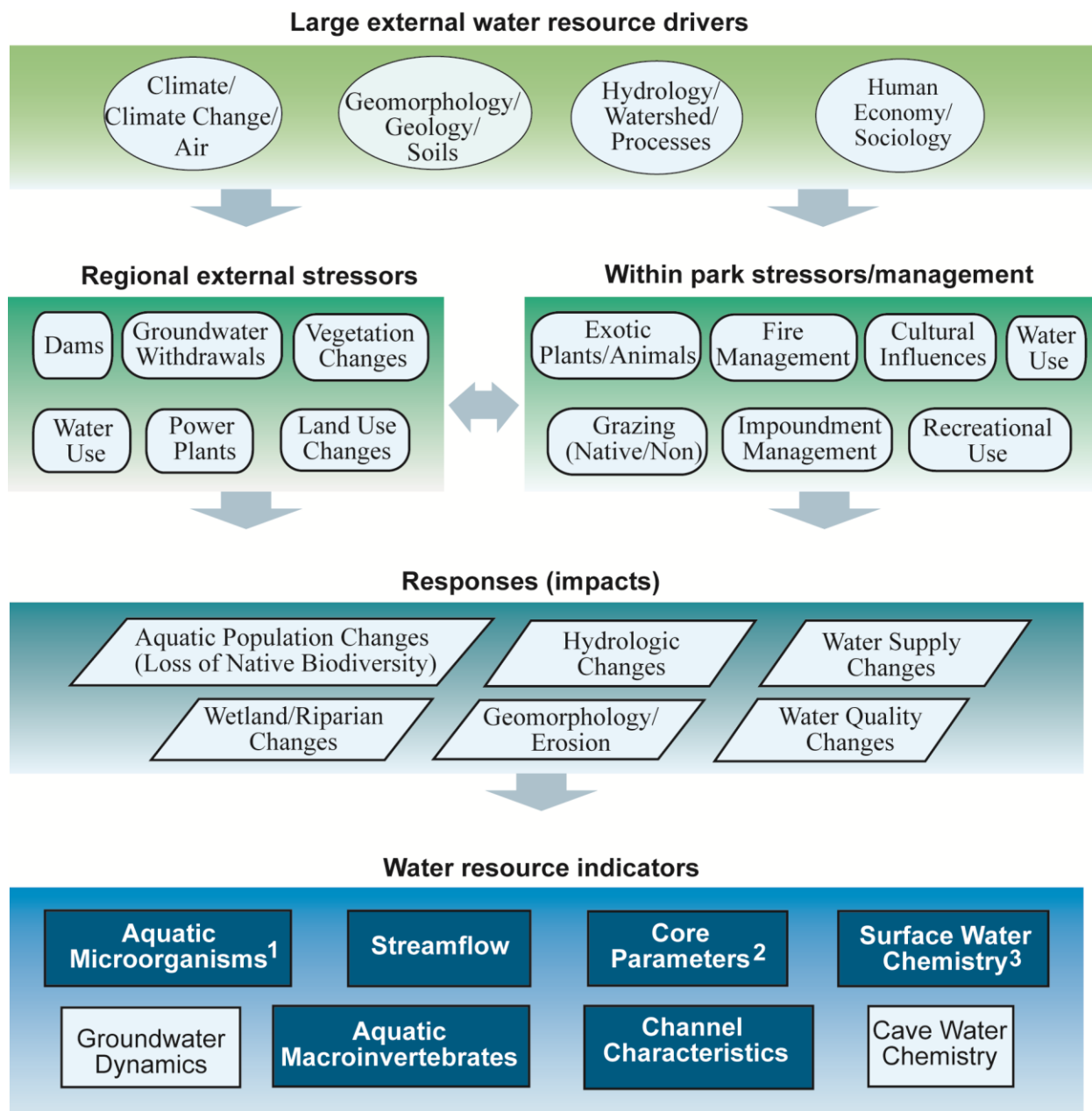
Anthropogenic stressors at the regional level can result from agricultural and urban activities within a watershed, such as alterations to hydrologic regimes through damming, irrigation and withdrawals, and cultural policies that affect water quality (Postel and Richter 2003). Dams constructed for

recreational activities, hydroelectric power, and water supplies have blocked sediment transport and reduced scouring events, resulting in loss of aquatic habitat and degradation and reduction in backwater habitats. Dams and channelization have altered sediment transfer in the Missouri River system (NRC 2002) and are of concern to DETO, Fort Laramie NHS (FOLA), Fort Union Trading Post NHS (FOUS), Knife River Indian Villages NHS (KNRI), and Missouri NRR (MNRR; Table 2).

Along with such direct alterations, land-use changes associated with anthropogenic activities in the Great Plains have affected water quality, altered hydrographs, affected riparian flora and fauna, and modified streambed structure and function (Longo and Yoskowitz 2002). In addition, the occurrence of pesticides and fertilizers in waters associated with agriculture adjacent to parks are water quality concerns for AGFO, BADL, DETO, KNRI, and SCBL (Table 2).

Climate change can be an added stressor to aquatic ecosystems. The Northern Great Plains temperatures have risen more than 2 °F in the past century (National Assessment Team 2000). Increased air temperature can alter precipitation patterns and have direct effects on the composition, structure, and functioning of aquatic ecosystems by limiting moisture availability and altering fluvial geomorphic processes (Scott et al. 2005).

Within a park, cultural effects and recreational use also may affect hydrologic processes and physical habitat. Park management decisions, such as containment of large-scale fires (Rieman et al. 2003) and emplacement of impoundments, can affect the dynamics of water resources. Furthermore, naturally occurring processes such as geomorphologic changes can destabilize stream channel structure and substrate composition, increase sediment loading, and degrade the riparian habitat (Pollowy 1998). In addition, invasion by a predatory fish and a non-native iris at AGFO may have negatively affected water resources within the park unit (Table 2).



¹ Total coliforms and *Escherichia coli*.

² Dissolved oxygen, pH, specific conductivity, and water temperature.

³ Fuel components, nutrients, pesticides, or select trace metals.

Figure 2. Conceptual model showing drivers and stressors that influence water resources within NGPN park units (dark blue boxes denote indicators selected for monitoring).

Table 2. Summary of stressors regarding water quality concerns in NGPN park units. Historical data gathered in “Baseline Water Quality Inventory and Analysis Reports” by the National Park Service Water Resources Division (WRD).□

Park (Four Letter Alpha Code)	Water quality concerns and potential stressors of water resources
AGFO	Park managers are concerned about effects of upstream pesticide use, fertilizers, upstream water withdrawals for irrigation, and ranching inputs. In June 2009, a diesel spill into the Niobrara River occurred upstream from the park. High water flows in the 1990s allowed predatory northern pike (<i>Esox lucius</i>) to move into AGFO waters from Box Butte Reservoir. All but one native fish have been eliminated from AGFO (Stasiak et al. 2011). The invasive species yellow iris (<i>Iris pseudacorus</i>) has restricted the channel width. Stasiak et al. (2011) suggest that decay of all the organic material has lowered dissolved oxygen levels well below the accepted level of 5 mg/L during summer months. Increase in average pollution tolerance of invertebrates also indicates that aquatic ecosystem quality has declined since 1989 (Tronstad 2012).
BADL	Some historical samples from park streams had high turbidity and total coliform counts as well as elevated concentrations of sulfate, dissolved nitrite, copper, and lead. The Civilian Conservation Corps (CCC) Springs recharge area originates on private lands that receive high loads of pesticides and fertilizers. The ecological impacts of the artificial stock ponds maintained for bison watering are of concern.
DETO	WRD assessments have reported some historical values above Wyoming State standards for turbidity, fecal coliform, sulfate, and suspended cadmium values (Wyoming Department of Environmental Quality, variously dated). ¹ Currently (2012), the Belle Fourche River may be affected by inputs from private rangeland and herbicide use upstream of DETO. The State of Wyoming has listed this segment of Belle Fourche River as impaired due to high levels of fecal coliform (WYDEQ 2010). An upstream dam alters the hydrograph.
FOLA	From 1973 to 1980, water quality criteria were exceeded for turbidity, coliform counts, and metals in samples from the Laramie and North Platte rivers (Wyoming Department of Environmental Quality, variously dated). ¹ Dams upstream affect the Laramie and North Platte rivers. An irrigation canal south of the park affects park resources through seepage and other hydrological effects.
FOUS	The park straddles the Missouri River but owns property only above the high-water mark. The Fort Peck Dam upstream on the Missouri River alters the natural river hydrograph. South riverbank erosion jeopardizes the FOUS view shed and the park land base.
JECA	Cave resources and springs could be impacted if groundwater quality is altered or if leaks and overflows from the sewage system occur. Private septic systems have the potential to contaminate groundwater in parts of the Black Hills, including the JECA area.
KNRI	The Knife River may be affected by pesticide use, cultivation, and livestock operations upstream. The State of North Dakota has listed this segment of Knife River as impaired due to high levels of fecal coliform (North Dakota Department of Health, variously dated). ² Natural bank erosion threatens an archeological site. The Missouri River borders the park but mostly is outside the park boundary.
MNRR	Effects of dams on the Missouri River are the most important natural resource issues. Sandbar habitats have been lost because the dams block sediment transport and reduce scouring events. The loss of periodic inundation of the bottomlands may be affecting cottonwood regeneration and nutrient cycling. Bank erosion continues to be a concern, but bank stabilization is also a resource stressor. Degradation and reduction in backwater habitats may be affecting amphibians and other wildlife. River management is complex due to the numerous agencies involved, with the U.S. Army Corps of Engineers having primary management authority for the river. Given the intense agricultural land use surrounding the MNRR, some Nebraska tributaries are listed by the State as impaired by <i>Escherichia coli</i> , selenium, and fish consumption advisory (Nebraska State Department of Water Quality, variously dated). ³ The State of South Dakota lists certain tributaries impaired by total suspended solids (South Dakota Department of Water Quality, variously dated). ⁴
MORU	Concentrations of arsenic >10 µg/L and high levels of nitrite plus nitrate were detected in surveyed MORU water resources (Heakin 2001). Current (2012) concerns include surface-water runoff from the parking lot and roads; perchlorate contamination from fireworks;

	and potential contamination from insecticides applied to reduce mountain pine beetle outbreaks.
NIOB	High pathogen levels have been reported in the recent past. Current (2012) pollution concerns include nonpoint inputs from cattle, the potential for additional point sources as more feedlots are established, and effects of the high number of canoeists. Dams below and at the upper end of the NIOB reach have altered hydrology and present barriers to fish movement. An increase in center-pivot irrigation in the uplands may affect hydrology.
SCBL	The North Platte River is affected by upstream dams, irrigation withdrawals, and input of pesticides, sediment, and nutrients. There is a concern about possible leakage of pesticides from canals in the park. Water quality and quantity at Scotts Spring is also a concern to park staff.
THRO	Water quality data collected from 1989 to 1995 indicated that many parameters exceeded screening criteria (North Dakota Department of Health, variously dated). ² The Little Missouri River is listed as impaired by <i>Escherichia coli</i> as it runs through the North Unit. Adjacent rangeland may affect water quality. Irrigation withdrawals occur upriver of the South Unit at a nearby golf course.
WICA	Developments and land-use practices may have reduced regional surface-water flows. In the past, fish kills have been observed in Highland Creek. Groundwater contamination in parts of the Black Hills may be caused by private septic systems. The primary concern of NPS with the proposed Southern Black Hills Water System is the potential for groundwater withdrawals to lower the water level of the Madison aquifer within the WICA underground lakes.

¹Wyoming Department of Environmental Quality, variously dated. Available at <http://deg.state.wy.us/wqd/watershed/surfacestandards/index.asp> (accessed 05 February 2013).

² North Dakota Department of Health, variously dated. Available at <http://www.ndhealth.gov/WQ/sw/> (accessed 05 February 2013).

³Nebraska Department of Environmental Quality, variously dated. Available at <http://www.ndeq.state.ne.us/> (accessed 05 February 2013).

⁴South Dakota Department of Environment and Natural Resources, variously dated. Available at <http://denr.sd.gov/des/sw/IntegratedReports.aspx> (accessed 05 February 2013).

Selection of Indicators for Monitoring Water Resources in NGPN Parks

Prioritization of Water Resources as a Vital Sign

Because of the magnitude of regional and within park stressors, the NGPN acknowledged that it was not financially feasible to conduct long-term monitoring for all the existing Vital Sign indicators. NGPN held scoping meetings at each park to identify a list of potential Vital Signs for NGPN to monitor. In 2002 and 2003, NGPN staff, Technical Committee, and Board of Directors concluded that vegetation and water quality were the top priority Vital Signs for the NGPN (Gitzen et al. 2010).

NGPN held a Vital Signs Selection Meeting in 2005 with park resource managers and external experts to prioritize the many potential Vital Signs identified for monitoring by NGPN. The 124 Vital Signs identified prior to the meeting were scored by considering the five Washington Office goals of park management, ecological significance, feasibility, success at addressing these goals, and the importance of the Vital Signs to NGPN partners. This selection process affirmed that water quality was a high priority for NGPN park units. In December 2008, the NGPN and the U.S. Geological Survey (USGS) South Dakota Water Science Center (WSC) hosted a Water Resources Workshop to prioritize the important waterbodies within each park and to rank water resource concerns regarding water quality indicators.

Selection of Primary Indicators for Measurement of Water Quality

The NGPN initially examined the physical, chemical, and biological elements and processes of the natural aquatic systems that represent the overall condition of water resources within park units. A subset of monitoring attributes that are particularly information-rich were then selected to provide an indication of the quality, health, or integrity of the aquatic ecosystems (Noon 2003).

The core parameters, including water temperature, dissolved oxygen (DO), specific conductivity, and pH, were considered by the NGPN as primary indicators of aquatic health (Table 6). Water temperature is affected by solar radiation, air temperature, land use, vegetative cover, and the depth of the waterbody. Increases in water temperatures alter the fundamental ecological processes and distribution of aquatic species. DO, a measure of the amount of oxygen in the water column, is considered an important indicator of a waterbody's ability to support aquatic life, with most requiring an average value of >5.0 mg/L of oxygen to survive. DO in rivers and streams typically declines as the temperature increases and the streamflow decreases. As plant and animal material decays, bacteria in the water consume oxygen. For example, the increased vegetative biomass and the subsequent decay may contribute to the low DO levels at AGFO. Specific conductivity is the measure of the water's ability to conduct electricity. Conductivity indicates the amount of dissolved solids such as salts and minerals in the water and is sensitive to factors in the surrounding watershed. The pH is a measure of the relative amount of hydrogen and hydroxyl ions in the water; acidic water has more free hydrogen ions, whereas basic water has more free hydroxyl ions. The pH level is dependent on atmospheric deposition (acid rain) and the composition of surrounding rock. Different organisms flourish within different ranges of pH. Humans contribute to elevated pH primarily in the form of nutrient runoff (most commonly from fertilizers). Low pH affects physiological (biological)

functions of aquatic life through the reduction of enzyme activity and effectiveness (Farrel-Poe 2005).

Streamflow/discharge is also a critical indicator of the health of a lotic aquatic system. Changes in flow are indicators of changes in basin dynamics and land use. Stressors such as water withdrawals for irrigation purposes, changes in adjacent land use, and dams alter the hydrology of systems. Altered flow regimes can affect flood mitigation, groundwater recharge, flood plain habitat, aquatic species, nutrient transport, pollution attenuation, biological productivity, and recreational opportunities. An understanding of how stream levels and regimes are altered over time is necessary for informed river/stream management.

Integration with Other NGPN Monitoring Protocols

It is important for the NGPN to integrate the water quality monitoring design in a multidisciplinary, collaborative approach with other NPS Vital Sign protocols (Figure 3) and with other agencies. Water resources are an important part of dynamic ecosystems that are complex, unpredictable, and capable of exhibiting phases of rapid and catastrophic change that may affect other aspects of the biological environment. Because biological environments are continually changing across temporal and spatial scales (Figure 3), patterns of ecological variability may be apparent at one scale but not at other hierarchical scales (Kay 1994). As such, meaningful detection of ecosystem changes, including the hydrogeologic system, is dependent on measurements at appropriate spatial and temporal scales (Noss 1990; Morgan et al. 1994). The NGPN developed a monitoring design to measure indicators for water quality and, to the extent possible, implemented existing monitoring protocols established by Federal and State agencies that will facilitate scientifically proven methodologies, allow integration of data, and encourage communication among cooperating agencies.

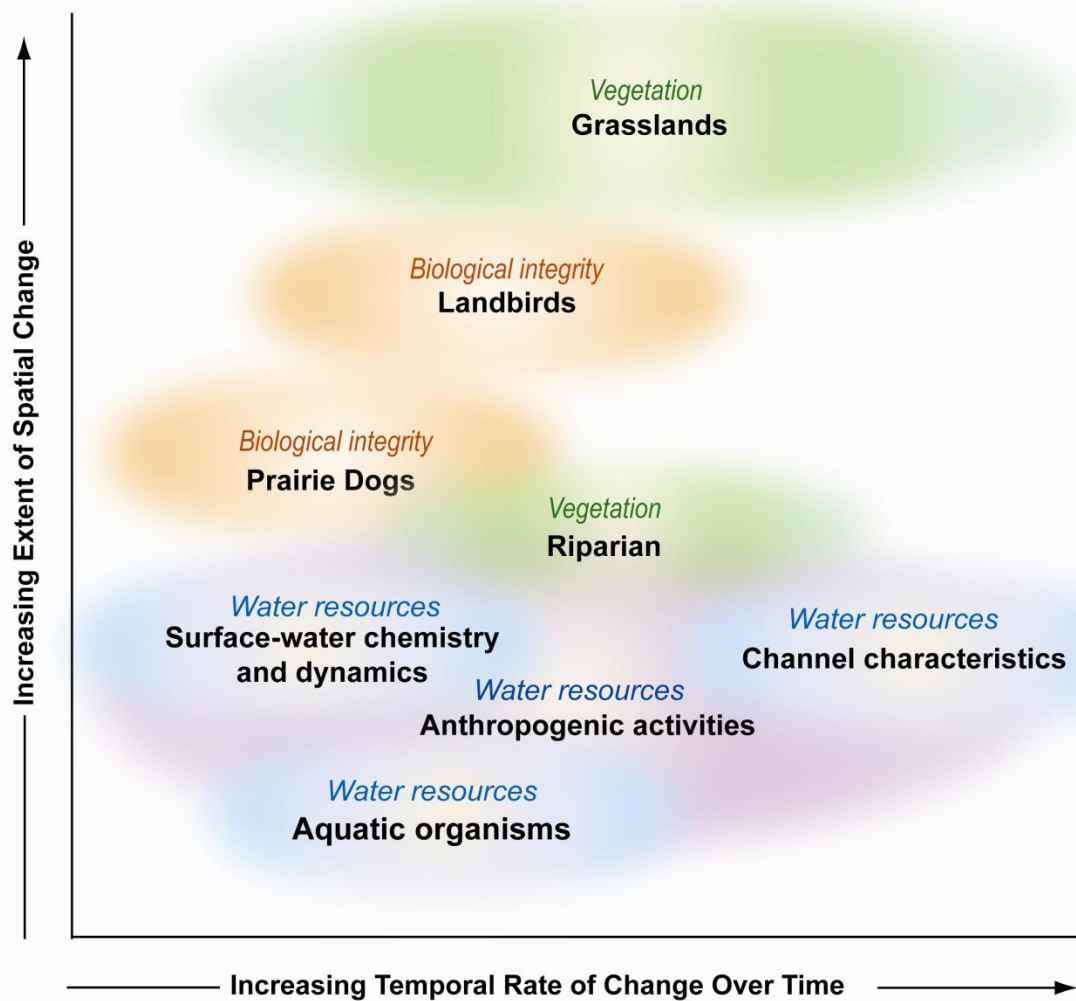


Figure 3. Overview of Vital Signs monitoring of ecosystems within the NGPN relative to the estimated spatial extent and temporal rate of change.

Overview of Water Resources in NGPN Park Units

The Missouri River is the longest river in the United States and drains about 530,000 mi² (1,372,694 km²) of the eastern Rocky Mountains and the Great Plains, and its drainage spans parts of nine U.S. States and two Canadian Provinces. A short segment of the Missouri River flows through FOUS (Table 1; Figure A5 in Appendix A). In 1978 and 1991, Congress set aside two free-flowing reaches by designating them as the MNRR and adding them to the National Wild and Scenic Rivers System. The MNRR comprises two sections separated by the Lewis and Clark Lake (Figure A8 in Appendix A). The 59-Mile District in the eastern part of the MNRR starts immediately downriver from Gavins Point Dam and continues downstream to Ponca, Nebraska (Figure A8 in Appendix A). In the western part of the MNRR, the 39-Mile District starts at Fort Randall Dam and continues downriver to Running Water, South Dakota (Figure A8 in Appendix A). The lower 20 miles of the Niobrara River and the lower 8 miles of Verdigre Creek also were designated as recreational rivers and are included in the 39-Mile District of the MNRR (Figure A8 in Appendix A). Additional information on the MNRR and its tributaries is available in “Northern Great Plains Network Water Quality Monitoring Protocol for Tributaries to the Missouri National Recreational River” (Rowe et al. 2013).

One of the major tributaries of the Missouri River is the Niobrara River, which begins in the high plains of eastern Wyoming and flows 535 miles to its confluence with the Missouri River (Figure 1). Springs and seeps feed the Niobrara River as it flows eastward through large expanses of grasslands. In 1991, Congress also designated 76 miles of the Niobrara River east of Valentine, Nebraska, as part of the National Wild and Scenic Rivers System. Although the Niobrara River has a low flow for much of its length, parts of the river are swift and cut through bedrock forming riffles, rapids, and waterfalls, such as Berry Falls, Fort Falls, and Smith Falls (Figure A10 in Appendix A). The Niobrara River also flows along the east–west axis of AGFO (Figure A1 in Appendix A); however, numerous tributaries within AGFO that feed the Niobrara River typically are dry.

The Little Missouri River also is a tributary of the Missouri River and is North Dakota’s only designated State Scenic River (<https://www.ndtourism.com/whatdo/activities/canoeing/>). Headwaters for the Little Missouri River are located in northeastern Wyoming (Figure 1), and the river flows undammed from south to north through parts of Wyoming, Montana, South Dakota, and the rugged badlands and rolling prairies of western North Dakota (Figure 1). The Little Missouri River within THRO bisects the South and North Units of the park (Figure A12 in Appendix A). Approximately 28 miles of the Little Missouri River are an important water resource within THRO, and 269 miles of intermittent streams (Table 1) provide substantial flow to the Little Missouri River during rainfall and snowmelt events.

Another tributary of the Missouri River is the Knife River that originates in the Badlands area of west-central North Dakota and flows east about 200 miles to its confluence with the Missouri River (Figure 1). Just upstream from the confluence with the Missouri River, the Knife River flows through the KNRI (Figure A7 in Appendix A).

The Belle Fourche River also is part of the Missouri River watershed via the Cheyenne River. The Belle Fourche River in northeastern Wyoming flows along the southern border of DETO (Figure A3

in Appendix A). Summer water releases from Keyhole Dam, located about 14 miles upstream from DETO, affect streamflows in the Belle Fourche River. In addition to the river, there are three active springs in DETO.

BADL comprises about 240,000 acres and is the largest park within the NGPN. Because of the arid conditions within this area, most of the creeks in the park are intermittent. The Civilian Conservation Corps (CCC) Spring and the associated spring complex creates a unique habitat in contrast to the water-poor areas of the park (Figure A2 in Appendix A). In addition, two large rivers flow along the periphery of BADL; the White River flows through the southeast corner of the Stronghold Unit, and the Cheyenne River flows to the west of the park (Figure 1; Figure A2 in Appendix A).

The North Platte River is a major tributary to the Platte River, which flows east into the Missouri River. This drainage historically has been an important route in the westward expansion of the United States and is an important water resource for two parks of cultural prominence, FOLA and SCBL (Figure 1; Figures A4 and Figure 11 in Appendix A). At FOLA, the Laramie River joins the North Platte as it continues southeasterly toward Nebraska (Figure A4 in Appendix A). The North Platte has been dammed several times to form reservoirs along its course, resulting in reduced river flow to a spring at the base of Scotts Bluff. Three canals transect SCBL (Figure A11 in Appendix A).

In addition, small-scale fluvial systems are an integral part of NGPN aquatic ecosystems. Hydrology within the Black Hills of South Dakota is greatly affected by geology (Driscoll and Carter 2001). MORU is located in the central core of the Black Hills, where three basins provide most of the drainage (Powell et al. 1973). The flow of intermittent streams Starling Basin Creek and Lafferty Gulch Creek depend on numerous small springs located throughout MORU (Powell et al. 1973; Figure A9 in Appendix A). Grizzly Bear Creek is a perennial stream; however, only about 200 feet of the stream touches the southeastern corner of MORU (Figure A9 in Appendix A).

WICA and JECA are located in the karst region of the Black Hills, South Dakota. Streams within WICA include Highland Creek, Beaver Creek, and Cold Spring Creek; the latter joins Beaver Creek shortly after entering the park (Figure A13 in Appendix A). Highland Creek and Beaver Creek generally lose their entire flow from leaking of surface water to the subsurface within the park unit (Hortness and Driscoll 1998). Surface-water resources within JECA are limited to Chokecherry Spring and Prairie Dog Spring (Figure A6 in Appendix A). Underground cave drips occur from the ceiling, and subterranean water collects in pools within the cave.

Previous Monitoring Efforts of NGPN Waterbodies

Previous water resource monitoring efforts in NGPN park units include (1) park-specific studies; (2) U.S. Environmental Protection Agency (USEPA) databases, which were used in the 1990s by the NPS Water Resources Division (WRD) to assemble water quality data; (3) USGS surface-water discharge data for select rivers and streams; (4) State water quality monitoring data; and (5) information from other Federal agencies. No park unit within NGPN currently has a comprehensive dataset that allows assessment of surface-water quality and long-term trends of park waterbodies.

Current water monitoring efforts in the NGPN parks consist of a few park-specific efforts and separate efforts by other agencies (Table 3). Starting in 1989, macroinvertebrates within the Niobrara River of AGFO were monitored by the NPS Prairie Cluster Prototype. In fiscal year 2010, the NGPN became responsible for this ongoing macroinvertebrate monitoring. Natural Resource Districts in western and central Nebraska have monitored groundwater levels and quality, and several NGPN park units have initiated measurement of static water levels of existing wells. To maximize efficiency, the NGPN will use relevant data from these monitoring efforts that provide information regarding water resources, such as data from existing USGS permanent streamgages.

Table 3. Current (2012) water quality monitoring in NGPN park units. The entity conducting monitoring is in parentheses. □

Park	Water Quality	Hydrology/Geomorphology
AGFO	Niobrara River macroinvertebrates Drinking-water contaminants (park)	Irrigation canal flow (Nebraska) Niobrara River flow (Nebraska) Groundwater level (park)
BADL	Drinking-water contaminants (park)	
DETO	Drinking-water contaminants (park)	Groundwater level (park)
FOLA	Laramie River: nitrates, temperature, water level, DO (USGS) Drinking water (park)	Bay well flow (Wyoming) Laramie River flow (USGS)
FOUS	Drinking-water contaminants (park)	Bank erosion (park)
JECA	Cave groundwater chloride and nitrate (park) Drinking-water contaminants (park)	Cave site drip-rate measurements (park)
KNRI	None	Missouri River flow (USGS) Bank erosion (park)
MNRR	Multiple parameters (multiple agencies)	Missouri River and tributary flow (U.S. Army Corps of Engineers (USACE), (USGS) Channel profile and imagery (USACE)
MORU	Drinking-water contaminants (park)	Grizzly Bear Creek peak flow (USGS)
NIOB	Niobrara River and tributaries: multiple parameters (park) 5-year surveys of pH, DO, phosphorous, nitrates, nitrites (Nebraska)	Niobrara River flow (USGS) Flow (park)
SCBL	None	None
THRO	Drinking-water contaminants (park)	Little Missouri River flow and tributary peak flow (USGS)
WICA	Beaver, Highland, and Cold Spring Creek: temperature, turbidity, DO, specific conductivity, pH, and salinity (park) Springs water chemistry (park) Drinking-water contaminants (park) Cave water quality (park)	Beaver Creek flow (USGS) Cave water level (park) Well groundwater level (park)

Status of NGPN Waterbodies Regarding the 303(d) List

In 1972, the Clean Water Act (CWA) was passed by Congress (USEPA 2012a) with the goal to restore and maintain the integrity of the Nation's surface waters. Section 303(d) of the CWA requires each State to assess relatively permanent, standing, or continuously flowing bodies of water every 2 years to determine if waterbodies are supporting designated beneficial uses or if additional pollution quality control measures are required (USEPA 2012b). Beneficial uses of the waterbodies are determined by each State during an analysis that determines actual use and potential uses of a waterbody, such as recreation. States prioritize the waters on the 303(d) list and develop Total Maximum Daily Loads (TMDL) for the impaired and threatened waters. TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still safely meet water quality standards (USEPA 2012c). Once the TMDL is approved or other changes to correct water quality problems are made, the USEPA allows States to remove waterbodies from their 303(d) list. Table 4 lists the State surface-water quality standards for select parameters and pathogens that are of concern to the NGPN park units. Table 5 lists the 2012 cycle waterbodies identified by the States as Category 5 waters, defined as waters where one or more beneficial uses have been determined to be impaired by one or more pollutants, and not all of the TMDLs have been developed (NDEQ 2012). These Category 5 waters constitute the Section 303(d) list subject to USEPA approval/disapproval (NDEQ 2012). Within the NGPN, the primary causes of 303(d) listing are pathogens (Table 5).

The Missouri River is the main artery of the major riverine system within the NGPN. Because the Missouri River provides a common boundary between part of Nebraska and South Dakota, beneficial uses are assigned and TMDLs are monitored by both States. The main stem of the Missouri River within the MNRR currently has no impairments; however, exceedances of water quality standards in tributaries to the Missouri River may impact the quality of water within the MNRR. Tributaries to the Missouri River within the 39-Mile District of Nebraska are predominantly impaired by *Escherichia coli* (*E. coli*; NDEQ 2012) and include the Niobrara River, Ponca Creek, Steel Creek, and the Verdigre Creek (Table 5; Figure A8 in Appendix A). Tributaries to the Missouri River within the 59-Mile District that exceed water quality standards include the James River in South Dakota as well as Bow Creek and Antelope Creek in Nebraska (SDDENR 2012; NDEQ 2012; Table 5; Figure A8 in Appendix A).

Although the Niobrara River within the NIOB was listed as impaired for *E. coli* through December 2005, Nebraska completed an *E. coli* TMDL for these waters that allowed Nebraska to remove the Niobrara River from its 303(d) list. For the 2012 cycle of the Nebraska 303(d) list, the Niobrara River within NIOB (Figure A10 in Appendix A) currently has no Category 5 impairments. An additional major waterbody in Nebraska, the North Platte River that flows along the northern boundary of SCBL, is impaired for exceedance of the *E. coli* standard (Figure A11 in Appendix A). Nebraska has also issued a fish consumption advisory this section of the North Platte River (Table 5).

In North Dakota the Little Missouri River flows through the North Unit and South Unit of THRO (Figure 1; Figure A12 in Appendix A). The Little Missouri River reach that runs through the North Unit is currently on the 303(d) list for exceedances of *E. coli* (NDDOH 2012; Table 5). Only a small

part of the Little Missouri River located inside the park's South Unit boundary is also listed as impaired for *E. coli*. Likewise, the Knife River from the confluence of Antelope Creek to the Missouri River is also listed as impaired by *E. coli* (Table 5; Figure A7 in Appendix A).

Select waterbody segments within NGPN South Dakota park units exceed water quality standards (Table 5). These waterbodies include the White River, which bisects the southeast corner of BADL (Stronghold Unit) and is included on the 303(d) list due to exceedance of fecal coliform, *E. coli*, and salinity; Grizzly Bear Creek, located in the southeastern part of MORU, which is on the 303(d) list for water temperature; and Highland Creek, which is within WICA in the southeastern part of the Black Hills and exceeds water quality standards for pH and temperature (SDDENR 2012; Figures A2, A9, and A13 in Appendix A).

DETO is the only NGPN park unit within Wyoming that currently is on the Wyoming 303(d) list. The Belle Fourche River is impaired due to fecal coliform spans between the confluence of the Belle Fourche River with Arch Creek to the south and with Sourdough Creek to the north (Table 5; Figure A3 in Appendix A).

Table 4. Listing of State surface-water quality standards for select parameters and coliforms measured within NGPN park units.

State	Conductivity/Total Dissolved Solids	Dissolved Oxygen	pH	Temperature	<i>Escherichia coli</i> (<i>E. coli</i>)	Fecal Coliform
Nebraska ¹	≤2,000 µS/cm	≥5.0 mg/L	6.5–9.0	Maximum limit is 22°C; 3 °C from natural background	Season geometric mean <126/100 mL	Not reported
North Dakota ^{2,3}	≤2,000 µS/cm	≥5.0 mg/L	6.5–9.0	<29.4 °C	Swimming areas <235/100 mL; body contact <298/100 mL; light body contact; <410/100 mL, infrequent body contact 576/100 mL	Not reported
South Dakota ⁴	2,500 µS/cm (30-day average); ≤4,375 µS/cm daily maximum	≥6.0 mg/L	6.5–9.0	<18.3 °C	≤630/100 mL geometric mean or ≤1,178 in a single sample	≤1,000/100 mL geometric mean or ≤2,000 single sample
Wyoming ^{5,6}	Not reported	≥5.0 mg/L	6.5–9.0	Change from natural <2.2 °C; <30 °C	<126/100 mL primary contact; <630/100 mL secondary contact	Not reported

¹NDEQ (2012).

²NDDOH (2012).

³The fecal coliform standard was replaced in 2012 with an *E. coli* standard in the North Dakota water quality standards (NDDOH 2012).

⁴SDDENR (2012).

⁵WYDEQ (2012).

⁶WYDEQ (2012). Note: this web site lists fecal coliform as a water quality standard for the State of Wyoming; however, *E. coli* is used for the 303(d) list (John Wagner, administrator of the Wyoming Department of Environmental Quality, personal communication, 26 November 2012).

Table 5. Category 5 impaired waterbodies¹ within NGPN park units. Standards for surface-water quality are established by each State and may vary among States.

Park	State List ID	Location	Impairment Description	Parent Impairment Description
Nebraska²				
MNRR, 39-Mile District	NE-NI2-10000	Niobrara River from Butte, NE, to Missouri River; includes USGS streamgage near Verdel, NE	Hazardous index compounds	Fish consumption advisory
MNRR, 39-Mile District	NE-NI1-10100	Ponca Creek from Spencer, NE, to Missouri River, NE	<i>Escherichia coli</i> Selenium	Pathogens Metals (other than mercury)
MNRR, 39-Mile District	NE-NI2-10800	Steel Creek downstream to Niobrara River, NE	<i>Escherichia coli</i>	Pathogens
MNRR, 39-Mile District	NE-NI2-10100	Verdigre Creek from Verdigre City downstream to Niobrara River	<i>Escherichia coli</i> Cause unknown	Pathogens Cause unknown
MNRR, 59-Mile District	NE-MT2-11300	Bow Creek	<i>Escherichia coli</i>	Pathogens
MNRR, 59-Mile District	NE-MT2-11800	Antelope Creek	Cause unknown	Cause unknown
SCBL	NE-NP3-10000	North Platte River from Tub Springs Drain downstream to confluence of Pumpkin Creek	Hazardous index compounds	Fish consumption advisory

Park	State List ID	Location	Impairment Description	Parent Impairment Description
North Dakota^{3,4}				
THRO, North Unit	ND-10110205-001-S_00	Little Missouri River from its confluence with Beaver Creek downstream to Highway 85	<i>Escherichia coli</i>	Pathogens
THRO, South Unit	ND-10110203-025-S_00	Little Missouri River from confluence with Deep Creek downstream to confluence with Andrew's Creek	<i>Escherichia coli</i>	Pathogens
KNRI	ND-10130201-002-S_00	Knife River between the confluence with Antelope Creek to Missouri River	<i>Escherichia coli</i>	Pathogens
South Dakota⁵				
BADL, Stronghold Unit	SD-WH-R-WHITE_02	White River from Willow Creek to Pass Creek	Fecal coliform <i>Escherichia coli</i> Salinity	Pathogens Pathogens Salinity/total dissolved solids/chlorides/ sulfates
MNRR, 59-Mile District	SD-JA-R-JAMES_11	James River from Yankton County line to mouth	Total suspended solids	Turbidity
MORU	SD-CH-R-GRIZZLY_BEAR_01_USGS	Grizzly Bear Creek near Keystone, SD	Water temperature	Temperature
WICA	SD-CH-R-HIGHLAND_01_USGS	Highland Creek near Pringle, SD	pH (high) Water temperature	pH/acidity/caustic conditions Temperature

Park	State List ID	Location	Impairment Description	Parent Impairment Description
Wyoming ⁶				
DETO	WYBF101202010904_00	Belle Fourche River from confluence with Arch Creek to confluence with Sourdough Creek	Fecal coliform	Pathogens

¹Category 5 waterbodies are where one or more beneficial uses are determined to be impaired by one or more pollutants and all of the TMDLs have not been developed. Category 5 waters constitute the Section 303(d) list subject to EPA approval/disapproval (NDEQ 2012).

²NDEQ (2012).

³NDDOH (2012).

⁴In 2012, the fecal coliform standard was replaced with an *E. coli* standard in the State water quality standards (NDDOH 2012).

⁵SDDENR (2012).

⁶WYDEQ (2012). Note: this web site lists fecal coliform as a water quality standard for the State of Wyoming; however, *E. coli* is used for the 303(d) list (John Wagner, administrator of the Wyoming Department of Environmental Quality, personal communication, 26 November 2012).

Objectives for Water Resource Monitoring

The overall goal of NGPN's water resource monitoring is to provide information that will allow park managers to make better informed decisions and to work more effectively with other agencies and entities for the benefit of park resources (Gitzen et al. 2010). The primary focus is on park-level inference, although opportunities for NGPN-wide syntheses may be explored as a secondary priority in the future. The goals of the NGPN water monitoring plan are to (1) implement a scientifically sound and temporally balanced monitoring design that documents the current status of selected waterbodies; (2) assess the current overall ecologic condition and health of selected waters relative to water resource indicators; and (3) provide a baseline for assessing long-term trends. To meet these goals, the NGPN will conduct long-term monitoring of water quality at selected waterbodies by addressing the following questions and measureable objectives.

Question 1: Is water quality improving, declining, or staying the same in NGPN Wadeable streams/ivers?

Measurable objective: Determine the status and long-term trends of core field parameters including DO, pH, specific conductivity, and water temperature in surface-water samples at selected NGPN park units during the ice-free season (Table 6). Wadeable streams are defined by the USEPA as streams, creeks, and small rivers shallow enough to be sampled using methods that involve wading into the water (http://water.epa.gov/type/rsl/monitoring/streamsurvey/web_qa_06.cfm#1; accessed 29 October 2013).

Justification: Core parameters are important indicators of the ability of a waterbody to sustain life and can be used to track changes in a system. Water quality affects the aquatic biota, but components of each riverine system vary through time as a result of natural and anthropogenic causes. Thus, determination of the patterns of variability among years is necessary to detect long-term trends. In addition, changes in these core parameters and streamflow potentially may be used as indicators of climate and land-use changes over time.

Question 2: How are the timing, duration, and magnitude of discharge changing in the NGPN Wadeable stream/river systems?

Measurable objective: Determine the status and trends in streamflow at high-priority river systems during the ice-free season (Table 6).

Justification: Measurement of surface-water flow, often quantified as discharge, is important because of its effect on water quality. For example, higher volumes of faster moving water churn atmospheric oxygen into the water, thus increasing DO. In addition, the rate of flow affects water temperature, which in turn affects other water quality parameters. Smaller volumes of slower moving water can heat up in the summer, and this warm water holds less DO than cold water. Typically the specific conductivity of stream water responds quickly to streamflow and shows a marked decrease with increasing flow (Burch et al. 1994).

Table 6. Surface-water quality indicators and the information provided by measurement of water quality core parameters of wadeable rivers/streams within NGPN park units.

Monitoring Protocol Indicator	Description of Indicators and Information Provided by Measurements
Water Quality Core Parameters	Ongoing monitoring of these constituents measure waterbody response to the environment and may qualify and quantify changes.
Dissolved Oxygen (DO)	The DO level, a measure of the amount of oxygen in the water column, is considered an important indicator of a waterbody's ability to support aquatic life. The DO in rivers and streams typically declines as temperature increases and as flow decreases; DO also responds to photosynthesis, resulting in natural variation during the day and additional natural variation through the season. The DO in water can vary over extended periods of time due to changes in the landscape or climate.
pH	The pH is a measure of the hydrogen ion concentration in a solution. A pH value <7 indicates that water is acidic, a value of 7 indicates that water is neutral, and a value >7 indicates that water is alkaline. The pH in surface waters typically ranges from 6.5 to 8.5, and rainfall is more acidic than surface water (pH ~5). The pH is dependent on atmospheric deposition (acid rain) and the composition of the surrounding rock. Changes in pH may indicate changes in the source water and within the watershed. Different organisms flourish within different ranges of pH.
Specific Conductivity	Specific conductance, a measured concentration of the water's ability to conduct electricity, typically is proportional to the dissolved major ions in the water such as calcium, magnesium, sodium, and sulfate. A change in specific conductance indicates a change in the concentration(s) of major ions. Small changes in specific conductance are common through the day and through the seasons.
Water Temperature	Water temperature is affected by solar radiation, air temperature, rainfall, flow dynamics, physiography of the waterbody, stream shading, land use/cover, and land development in the watershed. Water temperature monitoring indicates response to daily and annual climatic variations and may track short-term drought or long-term climate changes. Water temperature can indicate changes in water use, source, and flow dynamics. Aquatic organisms are dependent on specific temperature ranges for their optimum health and survival.
Water Supply	Monitoring of water supply provides information regarding climatic cycles or long-term changes as well as land- and water-use effects.
Streamflow	Streamflow is the volumetric discharge of the unit volume of water passing a given point on a river over a given time and is usually measured in cubic feet per second (ft³/s). Changes in stream discharge, levels, and velocity are indicators of changes in water use, water management, and short- and long-term climatic changes. Changes also may be related to other effects, such as declines in stream riparian cover or effects from invasive plant species. Documentation of stream discharge is used for interpretation of water quality data to determine trends over time.

Sampling Design

The sampling design for monitoring NGPN water quality was developed through an interactive process involving park natural resource managers, NGPN personnel, and USGS staff using historical data, pilot data collected from 2008 through 2010, and power analyses (Appendix B).

Index Monitoring Sites

Because of the cost of water monitoring equipment and the sampling effort, and because upstream–downstream spatial variation in water quality likely is much lower compared to attributes such as riparian or terrestrial vegetation, many water quality monitoring programs focus on index sites. An alternative monitoring approach is probability-based sampling, which allows assessment of spatial variation and direct statistical inference to the population from which sites are selected. Both monitoring approaches have advantages and limitations, and no single sampling program can address the management needs to build a robust dataset within budget constraints. Index sites rather than probability-based sampling were chosen for water quality monitoring for a variety of reasons: limited NGPN resources; general acceptance of index site approaches by water quality experts; pilot data indicating that spatial variation within reaches is generally low; and power analyses indicating that automated monitoring of index sites would be more effective than repeated discrete visits to complete probability samples of sites within each park.

Selection of NGPN Monitoring Sites

Water resources within NGPN parks vary greatly from perennial and ephemeral streams to large rivers, canals, springs, impoundments, and ground water. Financial constraints limited the type and number of sites selected for water quality monitoring within the park units. To attain the measurable objectives, the NGPN design predominantly will monitor surface-water quality.

As previously mentioned, the NGPN and the USGS South Dakota WSC held a workshop where natural resource managers from each park prioritized the waterbodies to monitor and indicators to measure. NGPN staff compiled the input from park units by developing rankings for criteria based on prioritization of waterbodies by park staff. An additional consideration for site selection was the location of a real-time USGS streamgage or a State-operated gaging station in close proximity to the sampling site to effectively evaluate the relation between streamflow and water quality characteristics (R. Gilliom, USGS National Water Quality Assessment Program, Sacramento, CA, personal communication, 18 November 2013). With these considerations, the highest priority NGPN monitoring sites included wadeable surface waters of the Niobrara River in AGFO, the Niobrara River within the NIOB, the Laramie River at FOLA, and the Little Missouri River in the THRO (Table 7). Segments of the Belle Fourche River in DETO and the Knife River in the KNRI are on the 303(d) list for impairment of water by fecal indicator bacteria. The NGPN will coordinate *E. coli* sampling at impaired sites with the USGS WSC and respective State agencies.

Table 7. Priority waterbodies and measurable objectives ranked by staff from NGPN park units. Number 1 indicates the highest NGPN priority. □

Park	#1 Park Priority Waterbody	#1 Park Priority Indicator	Wadeable Perennial Stream?	Streamgage?	303(d) Listed Waterbody for Pathogens?	NGPN Priority
AGFO	Niobrara River	Water Quality	Yes	State ¹	No	1
BADL	CCC Springs	Chemistry	No	No	No	3
DETO	Belle Fourche River	Fecal Indicator Bacteria	Yes	No	Yes	2
FOLA	Laramie River	Water Quality	Yes	USGS ²	No	1
FOUS	Missouri River	Bank Erosion	No	No	No	3
JECA	Cave	Cave Water	No	No	No	3
KNRI	Knife River	Water Quality ³	Yes	No	Yes	2
MNRR–59-Mile District	Bow Creek	Water Quality	Yes	No	Yes	1 ⁴
MNRR–39-Mile District	Niobrara River	Water Quality	Yes	USGS ⁵	No	2 ⁴
MORU	Starling Basin Creek	Chemistry	No	No	No	3
NIOB	Niobrara River	Water Quality	Yes	USGS ⁶	No	1
SCBL	North Platte River	Fecal Indicator Bacteria	No	No	No	3
THRO	Little Missouri River	Water Quality	Yes	USGS ⁷	Yes	1
WICA	Cave	Cave Water	No	No	No	3

¹NDEQ (2012), Streamflow Retrieval, Niobrara River at Agate Fossil Beds (Station ID 6454100).

²USGS (2013), Laramie River near Fort Laramie, Wyoming (USGS streamgage 06670500).

³Bank erosion is monitored by NPS staff and the Midwest Archeological Center.

⁴Park prioritized tributaries and selected Bow Creek as priority number 1 based on park's ownership of land; and the Niobrara River, the major tributary of the Missouri NRR 39-Mile District, as priority number 2 (Rowe et al. 2013).

⁵USGS (2013), Niobrara River near Verdel, Nebraska, in the 39-Mile District (USGS streamgage 06465500).

⁶USGS (2013), Niobrara River near Sparks, Nebraska (USGS streamgage 06461500).

⁷USGS (2013), Little Missouri River at Medora, North Dakota (at entrance to the park South Unit) (USGS streamgage 06336000).

The MNRR was an exception to the NGPN water quality monitoring of wadeable streams. Because of the size of the Missouri main stem, the NGPN water quality design for the MNRR focused on main-stem tributaries. The free-flowing reaches of the Missouri River are located on the Nebraska–South Dakota border. Consequently, the South Dakota Department of Environment and Natural Resources and the Nebraska Department of Environmental Quality each have monitoring designs for ambient water quality sampling on a monthly basis at select sites on the Missouri River and tributaries. In addition, the Missouri River and its tributaries are monitored by Federal and private entities. A detailed summary of existing and current monitoring efforts was prepared by the USGS to assist park staff in the final selection of sites to avoid duplication of sampling efforts by other agencies and entities. The park staff selected water quality monitoring of Bow Creek in the 59-Mile District and the Niobrara River in the 39-Mile District (Rowe et al. 2013).

Target Population in Space and Time

The target population is selected surface-water sites within each park unit for which statistical inference will be made regarding the status and trends of water quality (Särndal et al. 1992; Gitzen et al. 2010). Data from selected index sites provide a narrow scope of inference; however, continuous monitoring during the ice-free season (from about mid-April through mid-October) coupled with the long-term rotating monitoring will provide water quality data that supply statistical robustness yet meet the NGPN budget constraints.

Power Analyses

Power analyses were primarily based on 2009 and 2010 pilot water quality data (summary of statistical analyses is included in Appendix B). The focus of the initial analyses was on linear trends in monthly means under the simplified assumption that each month would be analyzed separately, specified for analytical tractability. These analyses were used to examine trade-offs and performances of alternative monitoring designs based on two trend scenarios: (1) power to detect a 2% trend (change) per year over 10 years; and (2) power to detect a 1% trend per year over 25 years.

Potential sampling designs were examined by NGPN staff and USGS personnel. The major designs include continuous monitoring, discrete sampling, and hybrids of the two monitoring types. Continuous monitoring, as used in this water quality design, designates that measurements are made at a select site at frequent intervals (e.g., every 15 minutes), providing a nearly continuous record of water quality during sonde deployment. Discrete sampling, as used in this water quality design, refers to a measurement at a select site for a stated number of times during a given timeframe. All designs are based on monitoring during the ice-free seasons for about 6 months. Power was assessed for eight design options (Table 8):

- 1) one site continuously monitored at short intervals (e.g., every 15 minutes) for 6 months every year;
- 2) one site continuously monitored for 6 months every 3 years (i.e., site is monitored in year 1, skipped in years 2 and 3, and remonitored in year 4);

- 3) two sites continuously monitored for 6 months every 3 years (i.e., sites are monitored in year 1, skipped in years 2 and 3, and remonitored in year 4);
- 4) five sites with discrete sampling two times each month every 2 of 3 years;
- 5) five sites with discrete sampling one time each month every 3 years;
- 6) five sites with discrete sampling two times each month every 3 years;
- 7) hybrid design, one site continuously monitored for 6 months every 3 years and, during the intervening 2 years, five sites with discrete sampling two times each month each year; and
- 8) hybrid design, one site continuously monitored for 6 months every 3 years and discrete sampling two times each month for 2 out of every 3 years.

Table 8. Alternative NGPN monitoring designs examined for power analyses. Sites would be monitored during ice-free months. □

Design	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
#1	C ₁	C ₁	C ₁	C ₁	C ₁	C ₁	C ₁
#2	C ₁			C ₁			C ₁
#3	C ₁ C ₂			C ₁ C ₂			C ₁ C ₂
#4	D ₅ -2/mo	D ₅ -2/mo		D ₅ -2/mo	D ₅ -2/mo		D ₅ -2/mo
#5	D ₅ -1/mo			D ₅ -1/mo			D ₅ -1/mo
#6	D ₅ -2/mo			D ₅ -2/mo			D ₅ -2/mo
#7	C ₁	D ₅ -2/mo	D ₅ -2/mo	C ₁	D ₅ -2/mo	D ₅ -2/mo	C ₁
#8	C ₁	D ₁ -2/mo	D ₁ -2/mo	C ₁	D ₁ -2/mo	D ₁ -2/mo	C ₁

BLANK CELL = no monitoring during specified time frame.

C₁ = continuously monitored at regular intervals (e.g., every 15 minutes) at one site.

C₁C₂ = two sites are continuously and simultaneously monitored in one park.

D₅ = discrete samples are collected at five different sites.

2/mo = two discrete samples collected each month.

D₁ = discrete samples collected at one site.

1/mo = one discrete sample collected each month.

For tractability and because discussions with USGS suggested a focus on monthly values (mean, median, minimum, and maximum), the power analysis focused on 1% and 2% trends in the average monthly parameter value for an arbitrary focal month (Appendix B). Power was estimated using a simulation approach, with power equal to the portion of simulations for a given scenario that detected a trend. Statistical results of power among the designs were compared (Tables B1–B3 in Appendix B).

Variance estimates used to simulate monitoring data were based on previous pilot work and on long-term historical USGS measurements from several streamgages in the region. The latter data provided the only source of information for estimating yearly variation; however, because these data generally consisted of only one to two measurements each month, resulting estimates of yearly variation likely are affected by diurnal and day-to-day variation. Thus, the highest yearly variance value used for each parameter is a worse-case scenario (Tables B1–B3 in Appendix B), especially given that future analyses can add covariates that could reduce the effect of yearly variation.

In an attempt to “simplify” Tables B1–B3 in Appendix B, the number of cells in all three tables that had a power ≥ 0.80 for the rapid change over 10 years and the gradual change over 25 years were summed (Table 9). Based primarily on the rapid change results, the designs were ranked from 1 to 3, with 1 representing the most robust designs (Table 9).

Continuous Monitoring

Design #1, for which sampling is conducted continuously every year at one site, was among the most robust designs (Table 9; Tables B1–B3 in Appendix B). Designs #2 and #3 were ranked as moderately robust. Continuous monitoring every third year may detect a 2% change per year if parameters have low within-year variability, such as for DO; however, the ability to detect a 2% change per year is uncertain. Continuous monitoring every third year likely would detect a long-term gradual change under most scenarios (Tables B1–B3 in Appendix B). To obtain meaningful minimum and maximum values each month, at least one site must be continuously monitored because a design with only discrete sampling will not capture the monthly distribution of measured parameter values. Continuous monitoring of a site could detect events that may affect the structure of the river system.

Discrete-only Sampling

Discrete-only sampling designs #4, #5, and #6 were the least powerful of the designs, particularly for the first decade of monitoring (Table 9; Tables B1–B3 in Appendix B). Because of the high index variability for most of the measured parameters, designs #4, #5, and #6 would offer little insight into temporal changes over 10 years. If the index variability is as high as observed during 2009–2010 sampling, the discrete-only designs may not detect a 1% change per year over 25 years (Tables B1–B3 in Appendix B).

Table 9. Water quality monitoring designs ranked on the percentage of cells that have a power ≥ 0.80 for each design number, and the total number of trips required for monitoring sites in each of the NGPN park units based on the 3-year sampling cycle design (Tables B1–B3 in Appendix B; Gitzen 2011).

Design ¹	Type of Sampling Design	Percentage of Cells with Power ≥ 0.80	Rank ²	Number of Trips ³
#1	Continuous	76%	1	33
#2	Continuous	38%	2	11
#3	Continuous	38%	2	11
#4	Discrete	19%	3	26
#5	Discrete	5%	3	7
#6	Discrete	5%	3	13
#7 a–c	Continuous/ Discrete	33%–71%	1 or 2	37
#8	Continuous/ Discrete	33%	2	37

¹Descriptions of sampling designs are included in Table 8.

²Rank 1 indicates most robust designs.

³The number of monitoring trips was based on previous NGPN pilot work during 2009 and 2010. Monitoring was completed within a 6-month timeframe during the ice-free season, from about mid-April through mid-October of each year.

Hybrid Monitoring

Designs #7a, #7b, and #8 were ranked as moderately robust (Table 8; Tables B1–B3 in Appendix B). Various analytical approaches were examined for hybrid designs (Appendix B). Design #7c of the meta-analysis approach was one of the most robust designs and could detect a 2% change per year during the first 10 years when yearly variance was moderate; however, the hybrid design likely would offer little insight into variability among sites in trends during the first 10 years due to discrete monitoring at select sites. After 25 years, continuous-only monitoring every third year would have sufficient power in nearly as many scenarios as the hybrid design. At that point, the hybrid design may have obtained sufficient data from discrete-only monitoring at sites to provide insights about variability in trends among sites and to assess whether data from the continuous-only monitoring at sites adequately capture broader trends in a park. The hybrid designs are not standard, however, and incorporating continuously monitored information in a statistical model to increase power/precision in analyses of discrete monitoring data is complicated. Thus, Gitzen (2011) recommended that the hybrid design should not be selected without additional discussion with statisticians to clarify analytical issues.

Sampling Design Rationale

Selection of the NGPN monitoring design must balance the trade-off between budget constraints and statistical robustness. To provide direction on potential budget constraints, the total number of trips required for each of the designs over the 3-year cycle was estimated (Table 9). Previous pilot work conducted by the NGPN indicated that continuous monitoring would require a site visit every 2 to 3 weeks, whereas discrete sampling required one to two visits to a site each month. Given the large number of trips required for design #1 and the hybrid designs, the less expensive designs would include designs #2 and #3, with continuous monitoring every third year, and discrete-only sampling designs #5 and #6. The NGPN water quality sampling design must produce a robust dataset for statistical analyses to examine the current status and long-term trends of waterbodies in selected NGPN park units; therefore, design #2, continuous monitoring of index sites every 3 years on a rotational basis, was selected to provide the NGPN with the most robust water quality dataset at a financially feasible cost. The NGPN will implement continuous monitoring at index sites every 3 years during the ice-free months.

Strengths and Limitations of the Sampling Design

The strengths of the NGPN water quality sampling design are economical and logistical feasibility and the provision of robust data. Sampling sites will be co-located with USGS real-time streamgages with the exception of Niobrara River, which will be co-located with Nebraska Department of Natural Resources station 6454100 (Niobrara River at Agate Fossil Beds). Documentation of streamflow will be used for interpretation of water quality data to determine trends over time and to calculate concentration loads. Furthermore, continuous monitoring every third year allows a staggered sampling scheme. For example, under the current funding regime, NGPN can sample selected streams/rivers within priority parks #1 and #2 within a 3-year cycle (Table 10). If funding becomes limited, NGPN can delay monitoring of the #2 priority systems and monitor only the #1 priority parks over the 3-year cycle. In this reduced budget scenario, the first year of the cycle would include THRO, the second year would remain the same, and the last year of the cycle would include AGFO

and NIOB sites (Table 10). The data from the first cycle of sampling will be assessed in fiscal year (FY) 2015 to determine if continuous monitoring is needed to reduce index variation.

Table 10. Prioritized 3-year water quality monitoring cycle of water resources at sites within NGPN park units from fiscal year 2013 through fiscal year 2018. Water quality monitoring of wadeable perennial streams will be completed by USGS Water Science Centers. □

Fiscal Year (FY)	Park	Water Quality Monitoring Site	NGPN Priority ¹	303(d) Listed Waterbody for Pathogens?	USGS Water Science Center
FY2013	DETO	Belle Fourche River at Devils Tower, WY (historical ² USGS streamgage 06427850)	2	Yes	Wyoming
	THRO	Little Missouri River at Medora, ND (USGS streamgage 06336000)	1	Yes	North Dakota
	KNRI	Knife River near Stanton, ND (new site at Highway 37 bridge)	2	Yes	North Dakota
FY2014	AGFO	Niobrara River at Agate Daily Streamflow Station near Harrison, NE (Nebraska Department of Natural Resources station 6454100)	1	No	Wyoming
	NIOB	Niobrara River near Sparks, NE (USGS streamgage 06461500)	1	No	Nebraska
	MNRR	Niobrara River near Verdel, NE (USGS streamgage 06465500)	2	No	Nebraska
FY2015	MNRR	Bow Creek near St. James, NE (historical ² USGS streamgage 06478518)	1	Yes	Nebraska
	FOLA	Laramie River near Ft. Laramie, WY (USGS streamgage 06670500)	1	No	Wyoming
FY16	Repeat FY2013				
FY17	Repeat FY2014				
FY18	Repeat FY2015				

¹Information provided from Table 7, "Priority waterbodies and measurable objectives ranked by staff from NGPN parks. Number 1 indicates the highest NGPN priority."

²Streamgage is no longer in operation.

The primary limitation for index monitoring sampling design is that sites are purposely selected rather than randomly selected. As such, statistical inference applies only to the selected sites, regardless of the number of sites monitored (Appendix B). Without random sampling or additional sampling to inform extrapolative models, direct statistical extrapolation from monitoring sites to other segments of the waterbody or to other waterbodies within the park cannot be made. Furthermore, random sampling of one to two sites within a park cannot result in meaningful inference due to the limited number of sites. If spatial variability is low and monitoring is expensive, however, data from purposely selected sites can provide trend assessments (e.g., weather stations, air quality stations).

Implementation of Water Quality Monitoring

The NGPN examined the cost of conducting water quality monitoring of core parameters by NGPN staff. Cost estimates were based on pilot projects conducted in 2009 and 2010 in which NGPN collected only the raw data but did not conduct any correction of these recorded data. The total cost of NGPN staff collecting core parameter data at two wadeable rivers was approximately \$170,000 each year. This total did not include the cost of data correction and the additional personnel costs of NGPN data management staff.

The NGPN then explored the possibility of having the USGS Nebraska, North Dakota, and Wyoming WSCs conduct continuous water quality sampling of core parameters at perennial NGPN streams and rivers. Each WSC provided NGPN with a draft budget that included data collection, sonde rental from the USGS Hydrologic Instrumentation Facility (HIF), travel, personnel, calibration, lab work, establishment of real-time delivery of water quality data, and correction of the collected data by experienced USGS data analysts. The highest estimated annual cost for USGS WSCs to continuously monitor the core parameter data and provide real-time and corrected data at three sites was roughly half of the cost for the NGPN to conduct the monitoring at two sites collecting only raw data. Thus, it is more cost effective to work with the existing USGS water programs than to duplicate these efforts. Consequently, NGPN will partner with the three WSCs to collect water quality at the selected parks using the recommended sampling schedule (Table 10).

Field Methods

Field Season Preparation

The Project Lead will coordinate the field season monitoring plan with the respective USGS WSCs and with park resource managers. Field work for each season will be scheduled well in advance of the April–October sampling window, and scheduling efforts will begin no later than January of the sampling year. The respective USGS WSC staff will request multiparameter sondes from the USGS HIF or from other vendors if necessary. The USGS WSC staff will ensure that all of the multiparameter sondes and streamflow equipment are properly calibrated prior to the initiation of data collection. USGS staff also will review the standard USGS protocols prior to field work to ensure quality data collection and staff safety (Rantz et al. 1982; Wagner et al. 2006; Gibbs et al. 2007; Turnipseed and Sauer 2010).

The logistics associated with permitting and compliance requirements for the upcoming field season will be initiated 5 months prior to data collection. Because most of the sampling sites are located within park boundaries, permits will be acquired through the NPS Research Permit and Reporting System online at <http://science.nature.nps.gov/research/ac/ResearchIndex>. The Bow Creek site associated with historical data is located in St. James, Nebraska, and will require additional permitting from State of Nebraska entities. Folders and electronic files will contain logistical information needed for each site, such as permission to access the site, compliance requirements, and maps.

Water Quality Monitoring

At each index site, continuous multiparameter sondes will be deployed to measure water quality core parameters including DO, pH, specific conductivity, and water temperature.

Quality assurance and quality control will adhere to the established USGS guidelines (Wagner et al. 2006). Both the water quality and streamflow data will be available as real-time data on the USGS National Water Information System (NWIS) website (<http://waterdata.usgs.gov/nwis/rt>) and subsequently linked to each of the park's websites.

The USGS staff will review sensor function and the real-time data download on a daily basis. Access to the real-time data allows USGS staff to verify the accurate transfer of raw field data to the database and to evaluate and identify erroneous data. The USGS staff will revisit each site every 3–4 weeks for general maintenance of the automated equipment; however, access to the real-time data allows the USGS field staff to recognize problems such as disruptions due to recording equipment malfunction, sedimentation, electrical disruption, debris, or vandalism. If disruptions occur, the USGS staff can schedule additional site visits, thus minimizing the loss of data.

During each site visit, USGS staff will conduct a site inspection and a side-by-side comparison with the in-the-water sonde and an independent field meter. Values of known standard solutions will be used pre- and post-calibration to help determine if fouling error and instrument drift have affected instrument measurements. This comparison allows checks of sensor-fouling errors and equipment drift that aid in the interpretation, correction, and grading of data (see standard operating procedure

[SOP] #3 in the accompanying document). The USGS staff will service and calibrate the sensors in the multiparameter sondes as needed.

Streamflow

Streamflow or discharge measurement is defined as the volumetric rate of the flow of water (volume per unit time). The USGS usually expresses streamflow in English dimensions of cubic feet per second (ft^3/s). Streamflow can be measured manually by computation of directly measured variables such as stream width, depth, and velocity (Turnipseed and Sauer 2010). Streamflow measurement is generally applied to the final result of the calculations. Estimation of streamflow involves (1) measuring stream stage, (2) obtaining periodic measurements of discharge, and (3) defining the stage–streamflow relation used to convert the stage into estimates of streamflow. A description of streamflow measurement is provided in “SOP 4: Measurement of Streamflow at Index Sites” (see accompanying document).

Assessment of streamflow for lotic streams is a critical component of water monitoring. Documentation of stream discharge is used for interpretation of water quality data when examining trends over time. For example, water withdrawals for irrigation purposes can reduce streamflow within a watershed, resulting in changes of core parameter levels. Thus, the USGS staff will conduct streamflow measurements at index sites during each visit using standard methods described by Turnipseed and Sauer (2010) as well as Rantz et al. (1982). Measurements along cross sections of a stream will provide a relation between the stage and streamflow. Streamflow measurements will be made while wading the stream when the depth and the velocity of water permit crossing of the stream without danger or injury to personnel. The tag line (or tape) is suspended across the channel perpendicular to the direction of streamflow, and increments are marked to define cells. Measurements of stream velocity will be made immediately downstream from the tag line in each cell to avoid disturbance of streambed. Depending on the particular site and existing conditions, stream velocity will be measured with a Price AA current meter, pygmy current meter, or an acoustic Doppler current profiler. The depth of flow is measured in each cell using the wading rod, an acoustic Doppler sensor, or other hydroacoustic current meter, and the flow in the cross section is determined by summing flows calculated in each cell along the tag line. The stage–discharge relation is used to convert the continuously recorded stage at the USGS streamgages and Nebraska gaging station into estimates of streamflow.

Because the Knife River, Belle Fourche River, and Bow Creek index sites are not equipped with streamgages, it is important for the USGS staff to collect streamflow data prior to sonde deployment, during each visit to the index sites, and after removal of the sondes at the end of the season, following Turnipseed and Sauer (2010). This information will provide discrete rather than continuous estimates of streamflow for these three sites.

After the Field Season

After completion of the water quality field work, USGS staff will clean all equipment and properly store it for winter. Electronic equipment, including streamflow meters, should have the batteries removed during the winter months to prevent corrosion and leaking. All postseason maintenance and

error checks of multiparameter sondes will be conducted by USGS staff, and the sondes will be returned to USGS HIF.

Data Management and Analysis

Data management and analysis of the water data is somewhat dependent on the type of data (time series versus discrete) collected by the USGS. Time-series data are a sequence of data points measured at uniform time intervals. An example of time-series data is the recording of water temperature values at a river site every 15 minutes on a continuous basis. In comparison, discrete data represent an individual count that is separate and distinct. For example, USGS technicians collect stage height data during each visit to a site; the time in between collection of these discrete data can range from 1 to 4 weeks.

Data Management

The NGPN's Data Management Plan (Appendix E in Gitzen et al. 2010) describes data management procedures in general terms. The primary purposes of data management are to (1) ensure accurate recording of water quality and streamflow data when they are collected in the field, (2) ensure correct transfer of the these data into an electronic database, (3) document water quality and streamflow data for future utility, and (4) maintain these datasets for access in perpetuity. The first two purposes will be accomplished by the USGS. The USGS will be providing the NGPN with copies of the raw time-series data for both water quality and streamflow as well as the corrected and approved final datasets as part of their deliverables to NGPN. The following sections outline the application of the general data management procedures to water quality monitoring. The SOP #5 Data Management and SOP #6 Data Analysis in the accompanying document describe these procedures in more detail.

Data Acquisition

Raw time-series water quality data will be collected by USGS WSCs using automated continuous multiparameter sondes at selected index sites. In addition, the USGS staff will manually collect streamflow data during each visit to the sites. Manual measurements of streamflow and gage height are used to supplement and verify the accuracy of the automatically recorded observations, as well as to compute streamflow based on gage height. At the end of each water year, each WSC will provide NGPN with electronic copies of the raw and the corrected/approved time-series data and streamflow data in the form of comma-separated value (CSV) files as well as metadata files, scanned data sheets, and station analysis reports as part of their deliverables (Figure 4).

Data Verification and Validation

Data verification is when the computerized data match the source data, and data validation is when the data are reviewed for range and logic errors. Both of these steps will be conducted by each respective USGS WSC for the water quality and streamflow data. The USGS field technicians will review and verify the raw data using Automated Data Processing System (ADAPS) or AQUARIUS software. Correction for sensor-fouling error and instrument-calibration drift will be calculated. Data are worked by the field technician then checked and reviewed by other USGS staff and, finally, set to "approved" in the database.

Metadata

Documentation of data is critical to ensure that datasets are adequate for long-term trend analyses. Metadata are defined as structured information about the content, quality, and condition of data and

will conform to the Federal Geographic Data Committee and NPS guidelines. The procedures for development of metadata are outlined in “Chapter 7 Data Documentation of the NGPN Data Management Plan” (Appendix E in Gitzen et al. 2010). The Data Manager and General Ecologist will create and update the metadata as changes are made to the protocol and as new information is reported each year.

Data Storage and Archiving

Water quality and streamflow time-series data (raw and approved) collected by the USGS will be stored on the local NGPN server and on the NPS Water Resource Division’s AQUARIUS Database in Denver (Figure 4). Likewise, the discrete water quality and lab measurement data collected at the monitoring stations will be entered as field visits in the NPS AQUARIUS database. The water resource component of the Natural Resource Challenge requires the Inventory and Monitoring (I&M) Networks to archive all physical, chemical, and biological water data in the National Park STOrage and RETrieval (NPSTORET) database that is also maintained by the NPS WRD. The desktop database application NPSTORET will be used to transfer the *E. coli* or other lab measurement data, at least annually, to the NPS WRD for upload to the NPSTORET database.

All USGS deliverables will be archived (read-only permissions) on the NGPN server and incorporated into the NGPN data backup rotation with off-site storage. Off-site storage provides the ability to restore files as old as 365 days (NPS 2011). Copies of the data are maintained at the NGPN office.

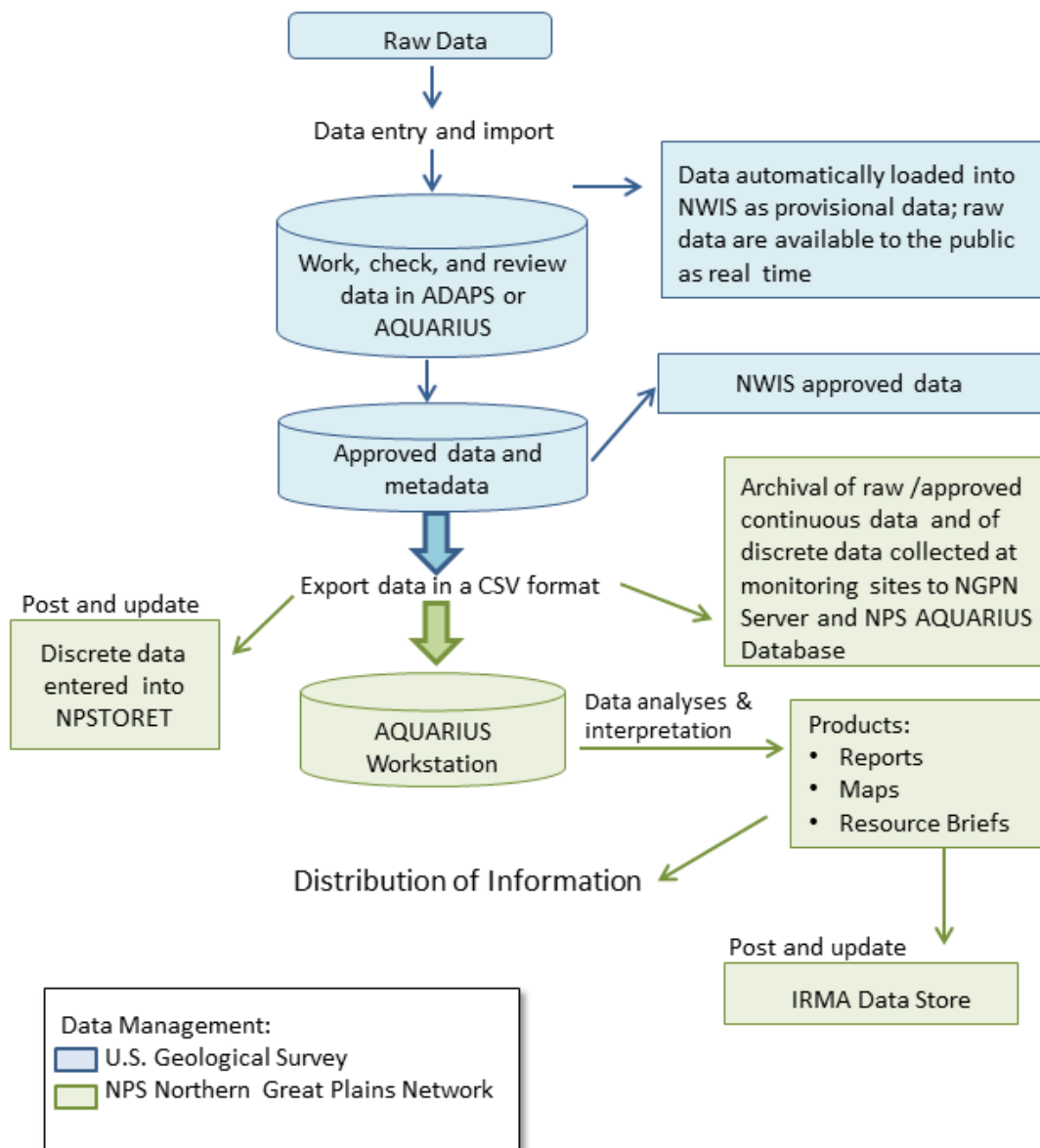


Figure 4. Diagram of data flow for water quality and streamflow data in select waterbodies in NGPN park units.

Data Analysis

Analysis and reporting of water quality data are an important part of providing natural resource managers with useful information regarding water resources. The continuous water data will be used to examine the status, seasonal and annual variability, and long-term water quality trends.

AQUARIUS Workstation by Aquatic Informatics (<http://aquaticinformatics.com/>) is the primary software environment that the NGPN will use for analysis of water quality data. The AQUARIUS Workstation tools are tailored to water systems and enable the NGPN to summarize and analyze the status and trends of the water time-series data. The volume of data generated by the multiparameter sondes collecting data at 15-minute intervals is large. For example, one sonde deployed from mid-April through mid-October can potentially produce 75,000 data points for the four core parameters. In addition to analysis of time-series data, the AQUARIUS Workstation will be used for analysis of the discrete measurements of streamflow data collected at index sites that are not co-located with an existing USGS streamgauge or State gaging station (i.e., Belle Fourche River, Knife River, and Bow Creek).

Status of Core Water Quality Parameters

When the NGPN receives the annually approved datasets from the USGS WSCs, the General Ecologist will generate report tables with descriptive statistics listing the mean, maximum, minimum, and degree of variation by month for each measured water quality parameter. The status of the core water parameters will be reported in a tabular form similar to the format in Table 11. Estimates of the proportion of observations exceeding State environmental regulatory thresholds will be calculated. In addition to tabular summaries, plots of time-series data and exceedance conditions for each parameter will convey the status of water quality: for example, time-series plots for DO measured at AGFO during 2010 (Figure 5). Plots of streamflow and each water quality parameter against time will also be generated in AQUARIUS to aid the interpretation of the water quality data.

Trend of Water Quality and Streamflow Data

After the first two cycles of data collection, the NGPN will initiate trend analyses for the water quality and the streamflow time-series data. For example, the first two cycles of data collection for the initial three parks (DETO, THRO, and KNRI) will be sampled in FY2013 and again in FY2016 (Table 10). The trend analyses for these three parks will be initiated after the 2016 data collection with the objective to detect gradual or rapid changes over time at a select site. Variation in water quality may be explained by accounting for seasonal variation in streamflow (Helsel and Hirsch 2002); however, seasonality often remains, even after streamflow effects have been removed (Hirsch et al. 1982). Because changes among seasons are a major source of variation for both water quality and streamflow, statistical analyses will initially use the Seasonal Kendall Test (Helsel and Hirsch 2002), which accounts for seasonality by computing the Mann-Kendall Test on each of the seasons separately, and then by combining the results (Helsel and Hirsch 2002). No comparisons are made across season boundaries. For example, May data at an index site will only be compared to May data at that site for another year. Kendall's S statistics for each season are summed to form the overall statistic (Helsel and Hirsch 2002). The trend analysis for water quality and streamflow will be performed using the AQUARIUS Workstation advanced statistics toolbox.

Table 11. Summary of descriptive statistics for water quality parameters for a spring and late summer sampling period at Niobrara River, 2010, at AGFO.

Descriptive Statistic	Temperature (°C)	pH	Specific Conductivity (µS/cm)	Dissolved Oxygen (mg/L)
Nebraska Department of Environmental Quality Standards ¹	Maximum limit is 22°C	6.5–9.0	≤2,000	≥5.0
Spring, May 17-20, 2010				
Number of measurements	277	277	277	277
Mean	14.9	8.2	414	7.0
Standard Deviation	1.46	0.2	5.0	02.
Median	14.7	8.2	414	6.6
Minimum	12.7	8.0	405	4.3
Maximum	19.4	8.6	423	11
% exceedance of standards	0	0	0	17%
Late Summer, August 23-25, 2010				
Number of measurements	165	165	165	165
Mean	18.4	8.3	400	5.1
Standard Deviation	1.87	0.2	02.7	0.78
Median	18.0	8.3	400	4.9
Minimum	15.7	8.1	396	4.1
Maximum	22.4	8.6	407	7.5
% exceedance of standards	5%	0	0	40%

¹NDEQ (2012)

Provisional Dissolved Oxygen Data, Niobrara River (AGFO), 2010

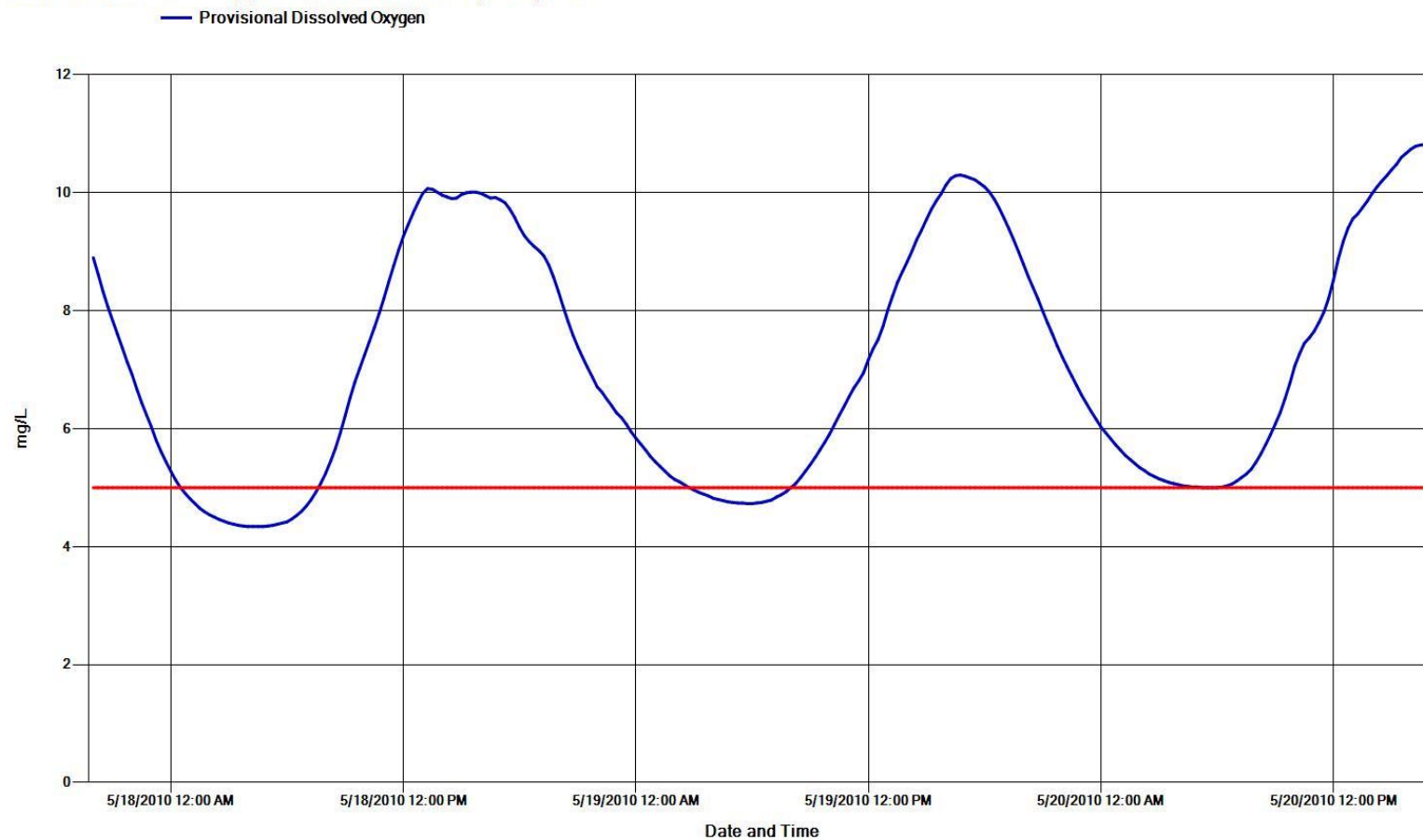


Figure 5. Example of summary plots of provisional DO data collected using In Situ Troll 9500 multiparameter sonde at AGFO during spring of 2010. The red line indicates the Nebraska Department of Environmental Quality DO regulatory threshold set at 5.0 mg/L (USEPA 2013).

Reporting Schedule and Format

A separate annual report will be generated for each park for data that were collected during the previous water year. Annual reports will be generated by NGPN staff and will provide summaries of the water quality data and streamflow data collected during the field season. Summaries will include the minimum, maximum, and mean of parameters on a monthly basis throughout the ice-free season. The reports also will include measurements of core parameters that exceeded the established State and (or) Federal regulatory thresholds (see example in Figure 5) and the site-specific USGS Station Analysis Report that includes the location, equipment, hydrologic conditions, and time frame for measurement at monitoring sites. In addition, the report will include channel characteristics, cross-sectional measurements, calibration records for equipment, computations based on meter to meter for each sensor, and remarks regarding parameters and conditions throughout the water year. Local weather conditions and storm events will also be examined, and the possible effects of these external factors on water quality records will be considered. Annual reports will contain an overview of necessary changes to the NGPN water quality protocol and SOPs for future monitoring efforts in park units.

The first water quality trend report for each park will be completed after two complete cycles of the sampling design. For example, the first two cycles of data collection for the second tier of parks (AGFO, NIOB, and MNRR) will be sampled in FY2014 and again in FY2017 (Table 10). The trend analyses for these three parks will be initiated after the 2017 data collection, and the report will include statistical analyses to determine trends in measured core parameters as well as the confidence estimates for the priority park units (Table 7). The first step in trend assessments will be to generate a graph of monthly means for a select parameter to compare variability versus time. The standard analysis was described above, but additional longitudinal analyses may incorporate climate/weather data to account for factors known to affect water parameters in the Northern Great Plains. Subsequent park trend reports will be completed after each data collection cycle. Format for these reports will follow the NPS Natural Resource Publications Management for the Natural Resource Technical Report Series. The template for this series is available at <http://www.nature.nps.gov/publications/NRPM/index.cfm>. All final reports will be presented to the park staff and uploaded to the NGPN website at <http://science.nature.nps.gov/im/units/ngpn>.

Personnel Requirement and Training

Personnel Requirements

The water quality protocol requires a full-time General Ecologist (project leader) to collaborate with personnel from the USGS North Dakota, Wyoming, and Nebraska WSCs, the NGPN I&M Network Coordinator, the Data Manager, and NGPN park resource managers for implementation of the protocol (Figure 6). Input from the NGPN Data Manager is necessary to develop and maintain database(s) for the water quality monitoring data generated by this protocol and to ensure that continuous data and field measurements are archived in the NPS AQUARIUS database and discrete lab measurements in NPSTORET. The roles and responsibilities of the NGPN staff are summarized in Table 12. A Quantitative Ecologist will work with General Ecologist to analyze trend data and prepare trend reports but will not be NGPN staff because these skills are not needed every year. The NGPN will dedicate funds every 6–12 years to obtain this expertise through another I&M network, the national I&M office, or outside partners such as the USGS or a university.

Training

The USGS WSCs are responsible for training of USGS hydrologists and technicians. In addition, the USGS WSCs will provide training as needed for the Project Lead for analysis of approved data.

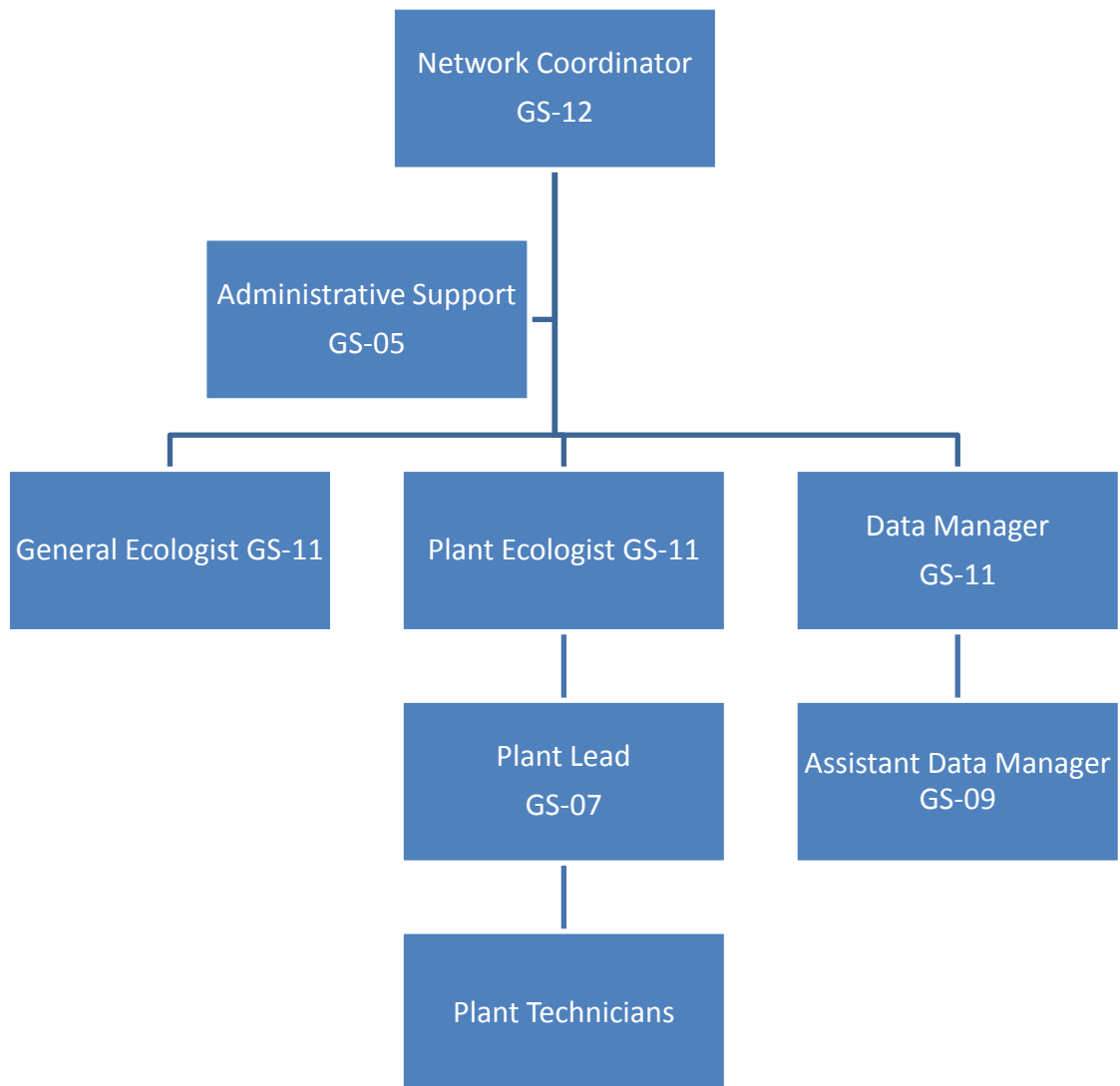


Figure 6. Staff structure for NGPN I&M program (modified from Gitzen et al. 2010).

Table 12. Roles and responsibilities for implementing the water quality monitoring program. Staff positions listed are from fiscal year 2012. □

Role	Responsibilities	Position
Project Lead	Provides project oversight and administration Serves as the Agreement Technical Representative for Interagency Agreements with USGS WSCs Collaborates with Network Coordinator on tracking project objectives, budget, and progress toward meeting monitoring objectives Facilitates communications between park and USGS Applies for NPS research permits Coordinates and ratifies changes to protocol Performs data summaries and analyses Certifies each season's data for quality and completeness Completes reports and other products according to schedule	NGPN General Ecologist
Hydrologists	Collects, reviews, and checks water data Assists with various States' Departments of Transportation for permitting processes Provides NGPN with corrected (approved) continuous water quality and streamflow data in a timely fashion Assists Project Lead and Data Manager with transfer and analysis of water data	USGS WSCs
Permit Coordinator	Assists with NPS permitting process for field collection of water samples	Park Resource Managers
Quantitative Ecologist	Works with General Ecologist to analyze data and prepare trend reports.	Outside Partner (USGS or University)
Data Manager	Consults on data management activities Facilitates review and posting of data, metadata, reports and other products to national databases according to the schedule Works with Project Lead to analyze spatial data and develop metadata for spatial data products Maintains and archives project records Serves as the primary steward of database and geographic information system data and products	NGPN Data Manager
Network Coordinator	Provides oversight for Project Leader Provides administration and budget support Consults on protocol review and implementation Reviews annual reports and trend reports	NGPN Coordinator

Operational Requirements

Annual Workload and Schedule

The annual workload for roles and tasks for the NGPN water quality monitoring protocol is presented in the preceding section “Roles and Responsibilities” (Table 12). SOPs #1 and #7 in the accompanying document provide a detailed description of the annual workload, including administrative tasks and report delivery. Annual implementation of work begins in January; the annual implementation schedule for this monitoring protocol is outlined in Table 13.

Budget

The NGPN estimated the costs associated with the 2012 water quality monitoring of core parameters by NGPN staff at two streams. The associated cost for measurement of core parameters was approximately \$170,000 per year, which did not include the cost of data correction and the additional personnel costs of NGPN data management staff. The NGPN then explored the possibility of having the USGS WSCs conduct continuous water quality monitoring at select sites within the NGPN streams. The USGS Nebraska, North Dakota, and Wyoming WSCs each provided a budget that included the cost of equipment, travel, personnel, calibration, laboratory work, establishment of real-time delivery of water quality data, and correction of collected data by USGS data analysts. The USGS cost estimates for continuous monitoring of water quality data at three sites for one water year was about one-half the cost of the NGPN collecting provisional data only at two sites for one water year; consequently, the NGPN decision was to partner with the USGS to collect and correct the water quality data. The annual operational budget for continuous water monitoring is estimated at about \$117,000 (Table 14). The total FY2012 funds for water quality monitoring provided to NGPN from WRD were about \$77,000; the remaining \$40,000 will come from NGPN monitoring dollars. The budget demonstrates that adequate resources are available for the NGPN water quality monitoring protocol that includes administration, field work, data management, and reporting (Table 14).

Equipment needs for this protocol are extensive and represent a considerable expense. The USGS WSCs will rent multiparameter sondes, if available, from HIF for each water year scheduled for monitoring by the NGPN; however, other rental sources will be contacted if equipment is not available through HIF. Additional equipment that may require rental includes streamflow measurement equipment, field laptops, and vehicle and safety equipment. In addition, equipment must be acquired for installation of data collection platforms to enable real-time data at select sites. The WSCs will also have recurring expenses over time for the purchase of calibration solutions for the multiparameter sondes.

Table 13. Annual implementation schedule for water quality and streamflow monitoring.

Month	Administration	Field Work	Data Management Reporting
January	USGS WSCs order sondes from HIF or other vendor. NGPN request Research Permits from the parks where data collection will take place this calendar year.		NGPN finalizes analysis of previous year's water data and exports previous year's approved data to NPSTORET.
February			NGPN submits annual water quality reports for each park sampled by WSCs in the previous year. Continuous data archived in the NPS AQUARIUS database and discrete lab measurements in NPSTORET.
March	Preseason meeting with WSCs. NGPN submit Investigator's Annual Reports to parks for work conducted last calendar year.	WSCs deploy automated continuous multiparameter sondes.	WSCs check and review real-time water data.
April		WSCs visit index sites.	WSCs check and review real-time water data.
May		WSCs visit index sites.	WSCs check and review real-time water data.
June		WSCs visit index sites.	WSCs check and review real-time water data.
July		WSCs visit index sites.	WSCs check and review real-time water data.
August		WSCs visit index sites.	WSCs check and review real-time water data.
September		WSCs visit index sites.	WSCs check and review real-time water data.
October		WSCs remove sondes.	WSCs check and review real-time water data. NGPN prepares the NGPN annual report and draft work plan. NGPN prepares budget for new fiscal year.
November	Postseason meeting with WSCs; WSCs return sondes to HIF.		WSCs provide NGPN approved water data.
December	NGPN submits multiyear USGS/NPS interagency agreement paperwork for next sampling cycle.		NGPN conducts preliminary analysis of current year's water quality and streamflow data in AQUARIUS.

Table 14. Annual budget for water quality monitoring in selected NGPN parks. Funding is based on fiscal year 2012 estimates.□

Expenditures	Comments	Cost in Dollars
Interagency agreements (USGS WSCs)	Continuous sampling at 2 or 3 parks each year	\$92,000
Project Leader (GS11) salary plus benefits	Project leader spends 30% of time on protocol	\$24,914
Software annual updates (AQUARIUS)	Support and maintenance agreement	\$825
TOTAL		\$117,739

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Glossary of Terms

303(d) list: a comprehensive public accounting of all impaired or threatened waterbodies within each State, regardless of the cause or source of the impairment or threat, as required biennially by the Clean Water Act.

Attributes: any living or nonliving feature or process of the environment that can be measured or estimated and provides insights into the state of the ecosystem. The term “indicator” is reserved for a subset of attributes particularly information-rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong.

Conceptual models: purposeful representations of reality that provide a mental picture of how something works to communicate that explanation to others.

Cross section: the profile of a river in which the width of the river is measured by using a tape measure stretched from one bank to the other bank at 90 degrees to the course of the river. A tape measure can be used to determine increment on the tape line (transect line). The vertical is the depth of the water measured by a wading rod placed “vertically” on the streambed at the center of each equally spaced increment. The depth and width of the “cell” can be measured in this way.

Continuous monitoring: as used in this water quality design, designates that measurements are made in a select site at frequent intervals, (e.g., every 15 minutes), providing a nearly continuous record of water quality during sonde deployment.

Discrete sampling: as used in this water quality design, refers to a measurement at a select site for a stated number of times during a given timeframe.

Designated beneficial uses: the desirable uses that water quality should support. In general, beneficial uses include drinking water supply, primary contact recreation (such as swimming), and aquatic life support. Each designated use has a unique set of water quality requirements or criteria that must be met for the use to be supported. A waterbody may have multiple beneficial uses. A waterbody is considered impaired when it does not attain the water quality standards needed to support its designated uses. Designated uses are a requirement for the States under the Clean Water Act.

Dissolved oxygen (DO): the measure of the amount of oxygen in the water column. DO in rivers and streams typically declines as the temperature increases and as flow decreases, and also responds to photosynthesis, resulting in natural variation during the day and additional natural variation through the season. DO in water can vary over extended periods due to changes in the landscape or climate. DO levels are considered as important indicators of a waterbody’s ability to support aquatic life.

Drivers: major external driving forces that have large-scale influences on natural systems. Drivers can be natural forces or anthropogenic.

Ecosystem: a spatially explicit unit of the Earth that includes all of the organisms, along with all components of the abiotic environment within its boundaries.

Impaired or threatened waterbody: any waterbody listed according to section 303(d) of the Clean Water Act. A waterbody is considered impaired if it does not attain water quality standards set by the State to ensure support of its designated uses. Standards may be violated due to an individual pollutant, multiple pollutants, thermal pollution, or an unknown cause of impairment. A waterbody is considered threatened if it currently attains water quality standards but is predicted to violate standards by the time the next 303(d) list is submitted to the U.S. Environmental Protection Agency.

Index site: a location determined to be relatively representative of the stream segment within park boundaries and logistically feasible to sample water chemistry parameters.

Indicators: a subset of monitoring attributes that are information-rich because their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong. Indicators are a selected subset of the physical, chemical, and biological elements and processes of natural systems selected to represent the overall health or condition of the system.

Inventory: an extensive point-in-time survey to determine the presence/absence, location, or condition of a biotic or abiotic resource.

Measures: specific feature(s) used to quantify an indicator, as specified in a sampling protocol. For example, pH, temperature, dissolved oxygen, and specific conductivity are all parameters that can be measured in waterbodies.

Metadata: describes the content, quality, condition, and other characteristics of data to help organize and maintain an organization's internal investment in spatial data; provide information about an organization's data holdings to data catalogues, clearinghouses, and brokerages; and provide information to process and interpret data received through a transfer from an external source.

Multiparameter sonde: the combination of several sensors, electrodes, or probe assemblies into a stand-alone piece of equipment that simultaneously measures several parameters. A multiparameter sonde is an instrument with algorithms that automatically compensate measurements (e.g., DO, pH, turbidity) for other parameters measured simultaneously, such as temperature and specific conductivity.

Northern Great Plains Network (NGPN): includes 13 constituent parks, their staffs, NPS staff stationed with the NGPN I&M office in Rapid City, South Dakota (I&M core staff), and other NPS and non-NPS collaborators developing and implementing the NGPN long-term monitoring and inventory program.

pH: the measure of the hydrogen ion concentration in a solution. pH values <7 indicate that water is acidic, a pH value of 7 indicates that water is neutral, and pH values >7 indicate that water is alkaline. The pH for surface water typically ranges from 6.5 to 8.5, and rainfall is more acidic (around 5). Changes in pH may provide indications of changes in the source water and within the

watershed. pH is also dependent on atmospheric deposition (acid rain) and the composition of the surrounding rock. Different organisms flourish within different ranges of pH.

Power analysis: The power of a statistical test is the probability that the test will reject a false null hypothesis or, in other words, will not make a Type II error. As power increases, the chances of a Type II error decrease and vice versa. The probability of a Type II error is referred to as b ; therefore, power is equal to $1 - b$. Power is a function of effect size or minimum detectable change, variance of the parameter (e.g., standard error of the mean), and sample size. A power analysis determines the probability of correctly rejecting a false null hypothesis given fixed values of effect size, variance, and sample size.

Protocols: Protocols are composed of two primary sections. The first section is a general narrative that provides an overview of the monitoring objectives, sampling design, methods, analysis, and reporting. The second section is a list of the Standard Operating Procedures that present step-by-step details of how to carry out each procedure.

Revisit design: schedule for visiting and measuring sample units (monitoring sites) across years.

Sampling design: method of choosing monitoring sites from the target population within each park and the schedule for collecting data from these sites.

Sensor fouling: chemical precipitates, stains, siltation, or biological growths that occur on the multiparameter sonde sensors.

Specific conductivity: the measurement of the water's ability to conduct electricity. Concentrations of conductance typically are proportional to the dissolved major ions in the water such as calcium, magnesium, sodium, and sulfate. A change in conductance is an indication of a change in the concentrations of these various major ions. Small changes in conductance are common through the day and through the seasons.

Status: the quantitative condition of a park resource across all monitoring sites at a single point in time or over a temporal window.

Stressors: physical, chemical, or biological perturbations to a system are either (1) foreign to a system or (2) natural to a system but applied at an excessive (or deficient) level. Stressors cause significant changes in the ecological components, patterns, and processes in natural systems. Examples include water withdrawal, pesticide use, timber harvesting, traffic emissions, stream acidification, trampling, poaching, land-use change, and air pollution.

Target population: collection of resources or area within each park about which we wish to make statistical inference from the data that are collected.

Temperature: water temperature is affected by solar radiation, air temperature, rainfall, flow dynamics, physiography of the waterbody (i.e., depth), land cover, stream shading, and the amount of development in the watershed. Water temperature monitoring indicates response to daily and annual climatic variations and may track short-term drought or long-term climate changes. Temperature can

also be an indicator of changes in water use, source, and flow dynamics. Aquatic organisms are dependent on specific temperature ranges for their optimum health and survival.

Total Maximum Daily Load (TMDL): the maximum amount of a pollutant that a body of water can receive while still meeting water quality standards regarding assigned beneficial uses.

Trend: directional change measured in resources by monitoring their condition over time. Trends can be measured by examining individual change (change experienced by individual sample units) or by examining net change (change in mean response of all sample units).

Vital Signs: as used by the National Park Service, a subset of physical, chemical, and biological elements and processes of park ecosystems selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. The monitored elements and processes are a subset of the total suite of natural resources that park managers are directed to preserve “unimpaired for future generations,” including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. Vital Signs may occur at any level of organization including landscape, community, population, or genetic level, and may be compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system), or functional (referring to ecological processes).

Appendix A. NGPN Hydrologic Unit Code Boundaries

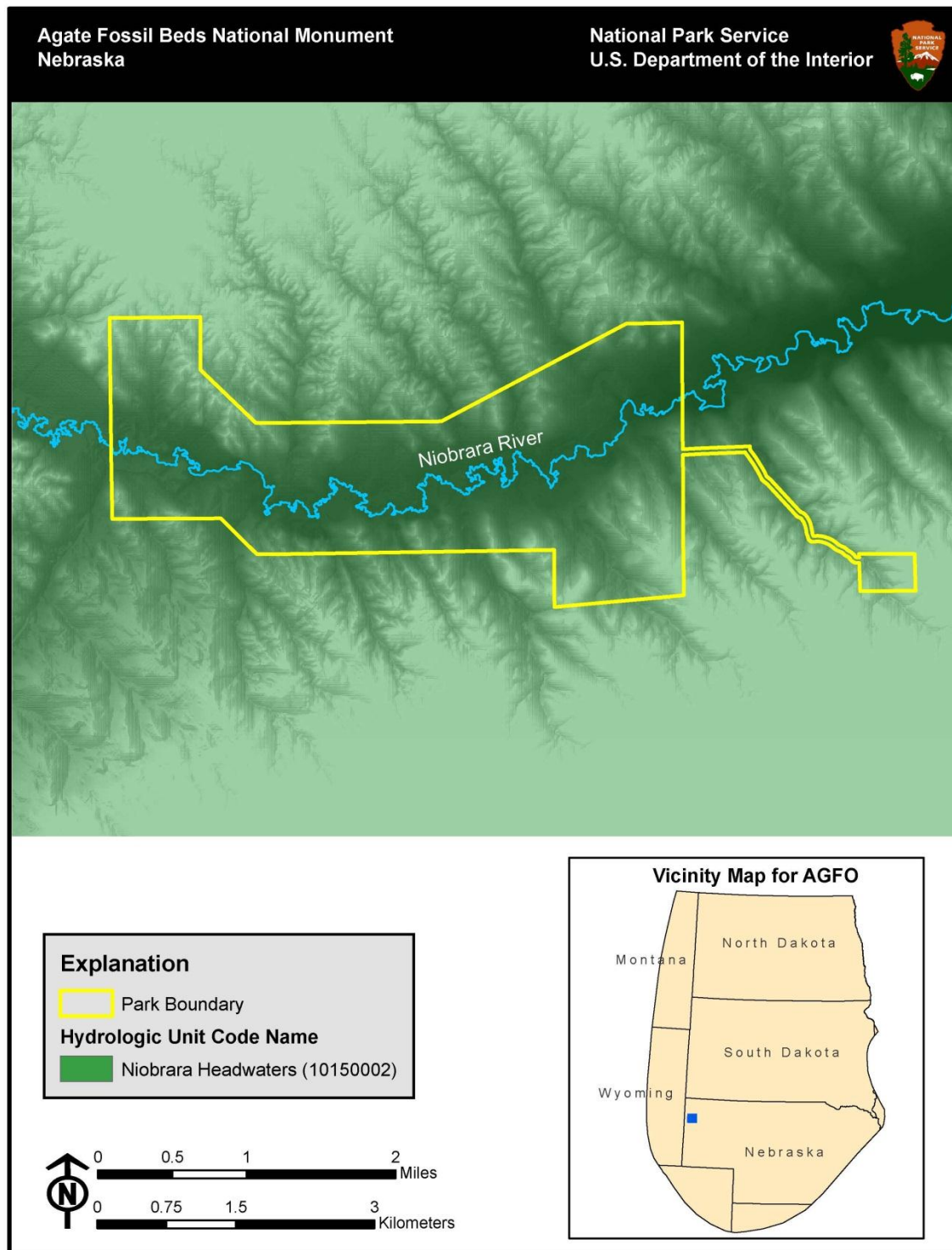


Figure A1. AGFO is located entirely within the Niobrara Headwaters Subbasin (8-digit Hydrologic Unit Code).

Appendix A. NGPN Hydrologic Unit Code Boundaries (continued).

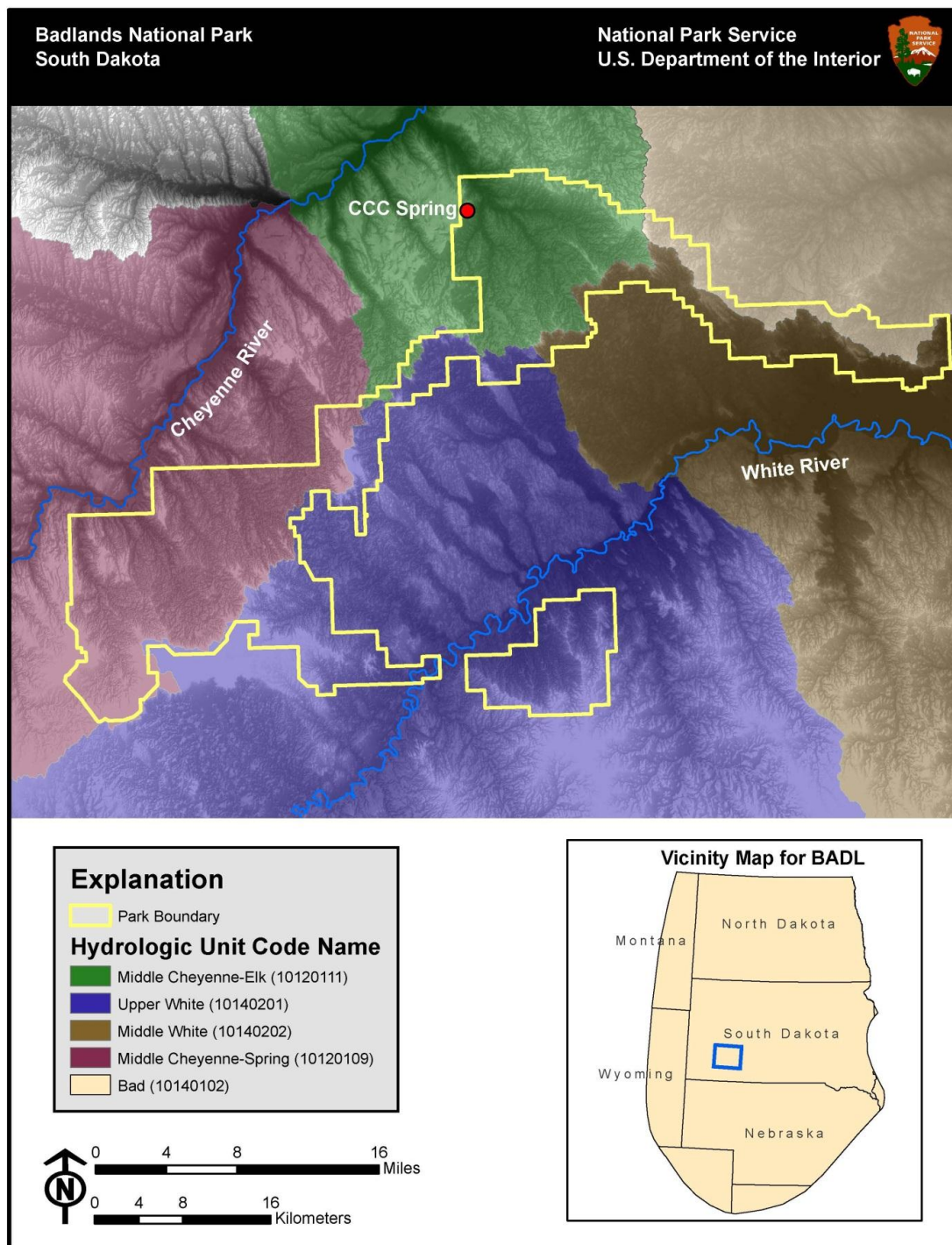


Figure A2. BADL is situated within five different subbasins (8-digit Hydrologic Unit Codes).

Appendix A. NGPN Hydrologic Unit Code Boundaries (continued).

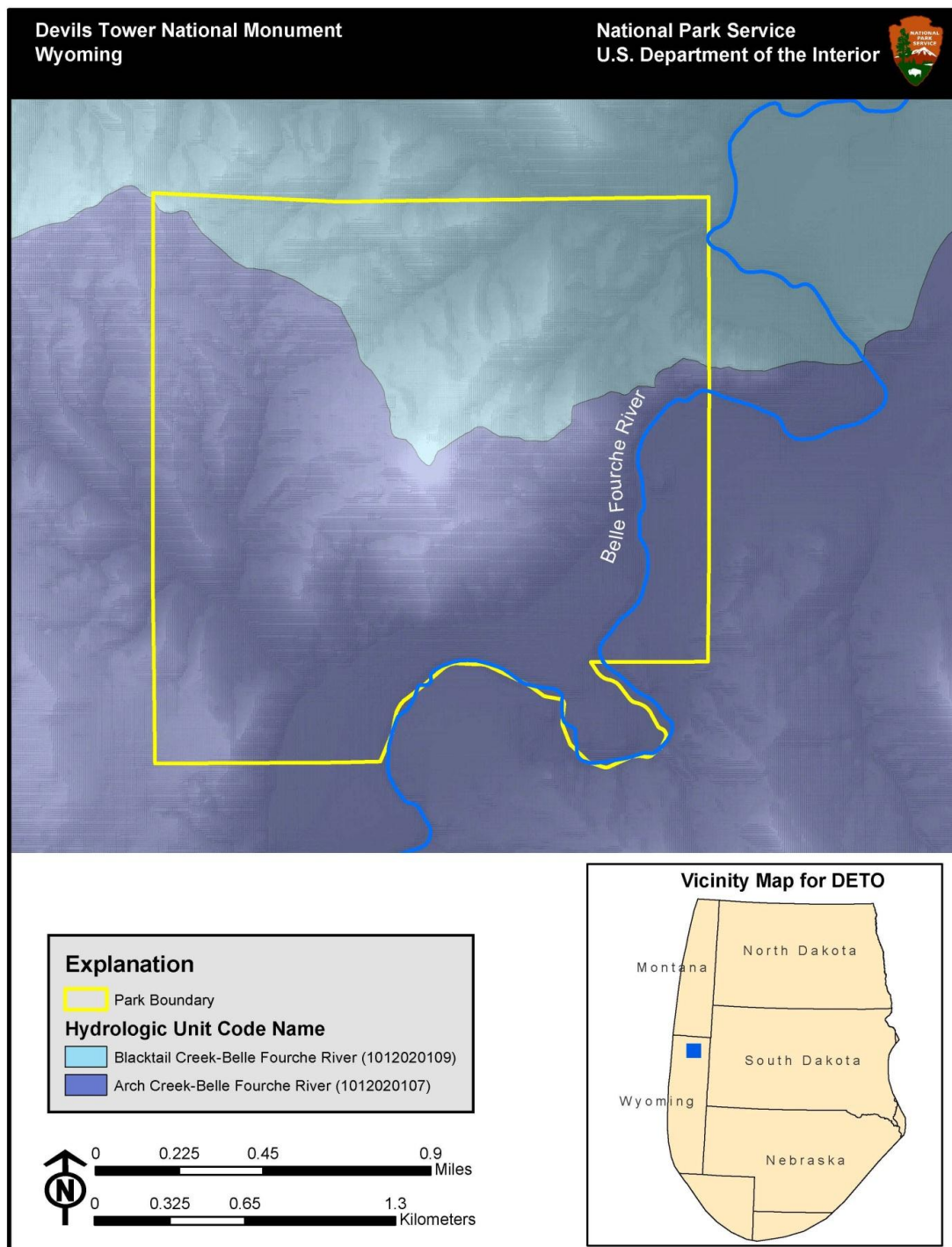


Figure A3. DETO is part of the Blacktail Creek–Belle Fourche River and the Arch Creek–Belle Fourche River watersheds (10-digit Hydrologic Unit Codes).

Appendix A. NGPN Hydrologic Unit Code Boundaries (continued).

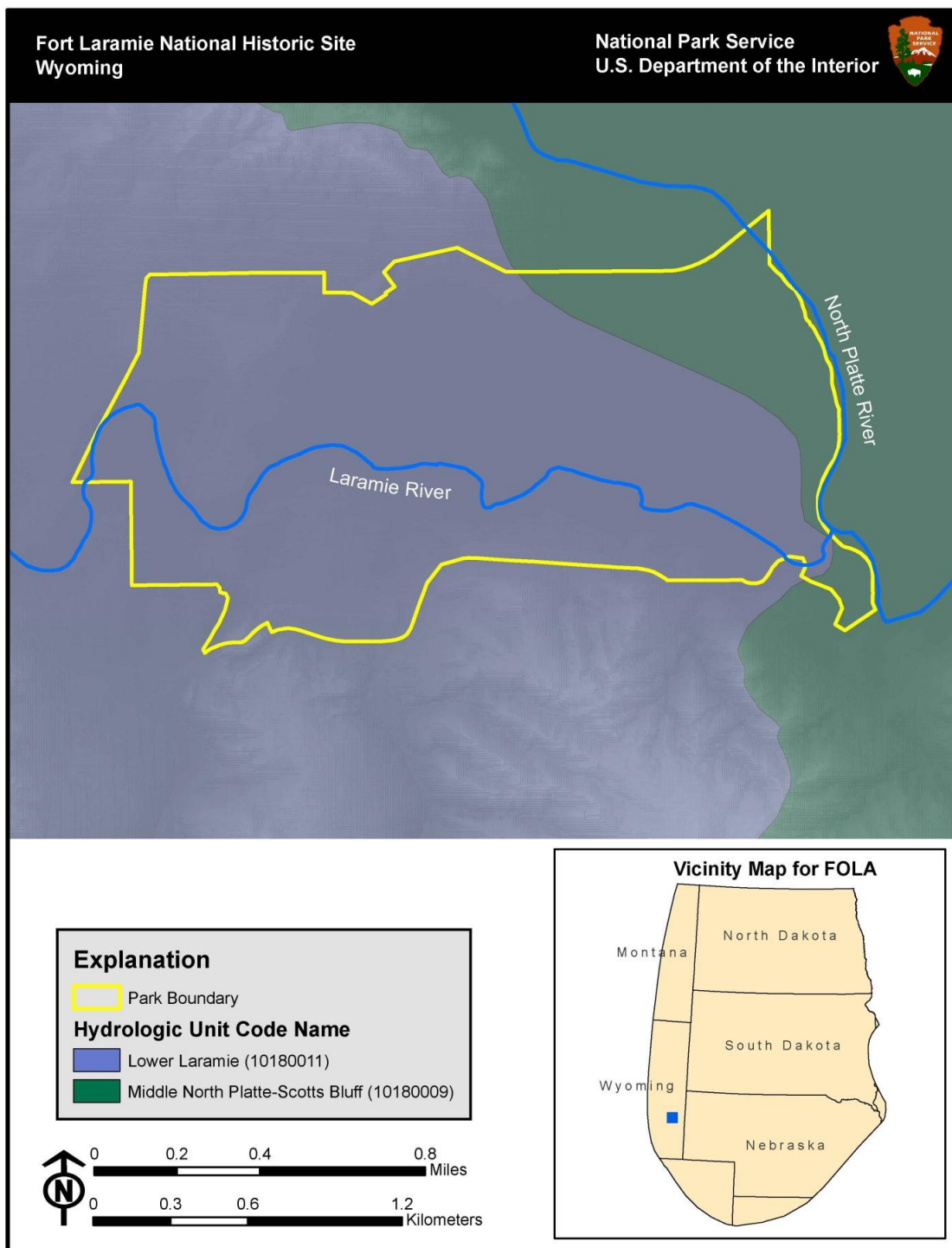


Figure A4. FOLA is located in the Lower Laramie and the Middle North Platte–Scotts Bluff Subbasins (8-digit Hydrologic Unit Codes).

Appendix A. NGPN Hydrologic Unit Code Boundaries (continued).

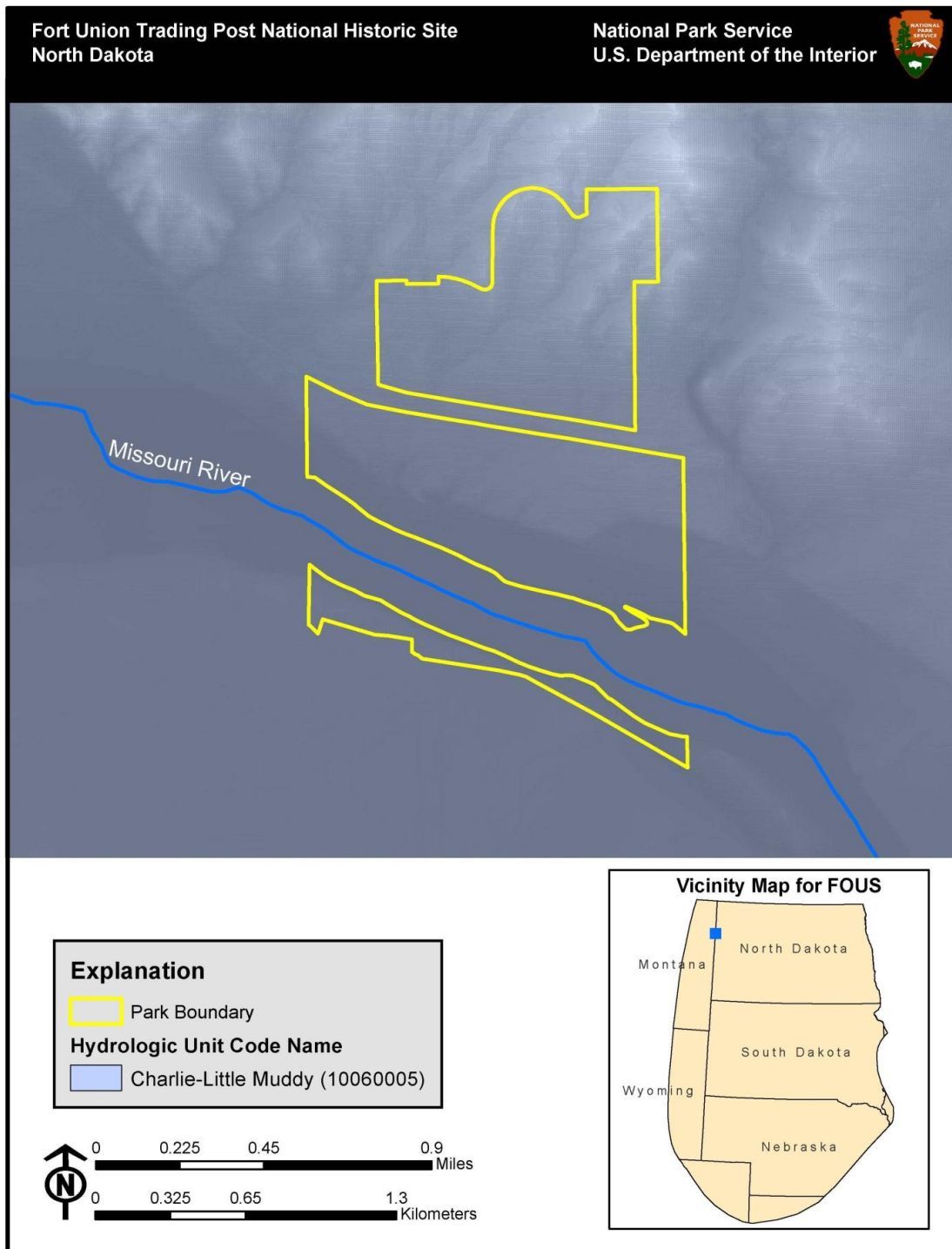


Figure A5. FOUS is situated entirely in the Charlie-Little Muddy Subbasin (8-digit Hydrologic Unit Code).

Appendix A. NGPN Hydrologic Unit Code Boundaries (continued).

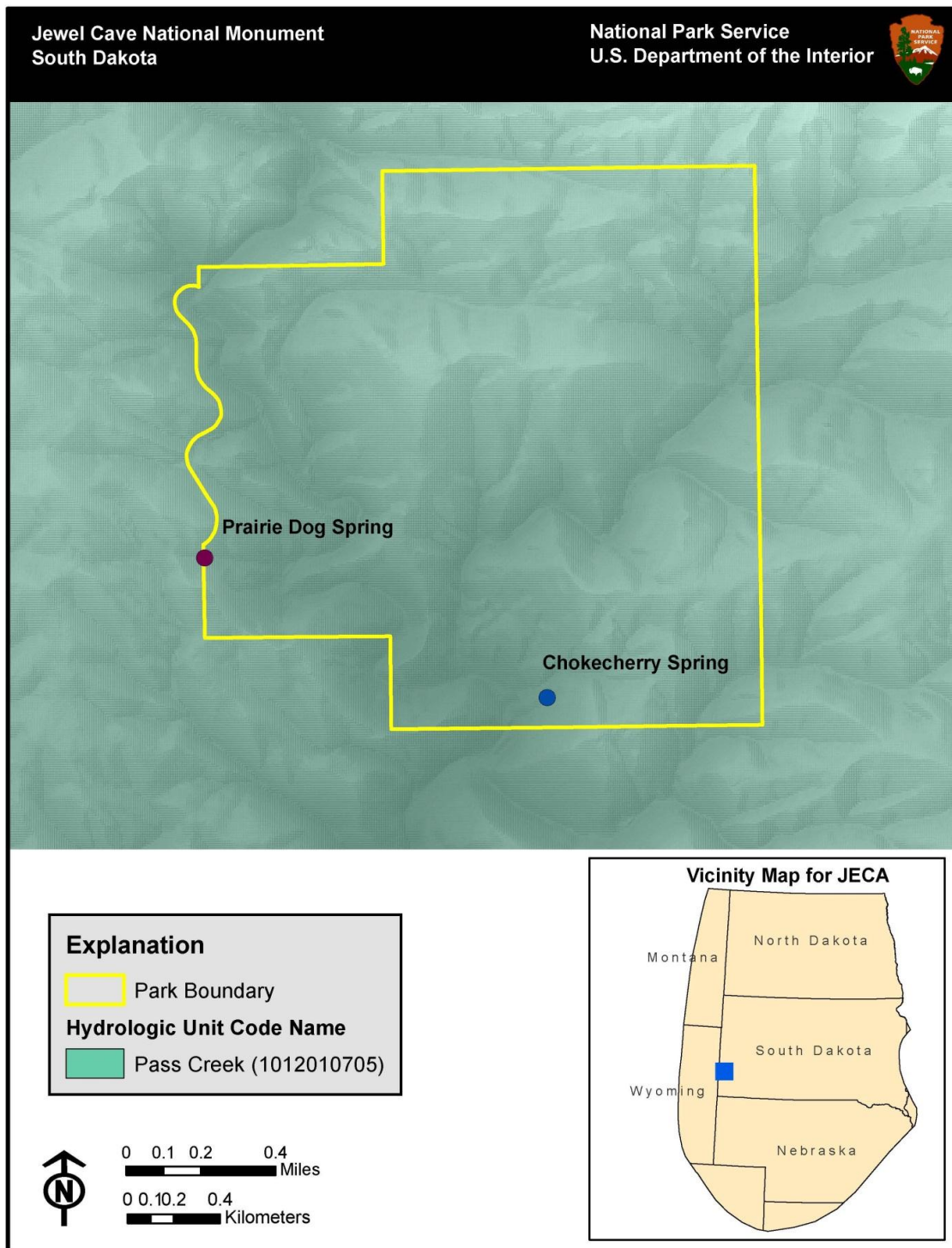


Figure A6. JECA is found in the Pass Creek Watershed (10-digit Hydrologic Unit Code).

Appendix A. NGPN Hydrologic Unit Code Boundaries (continued).

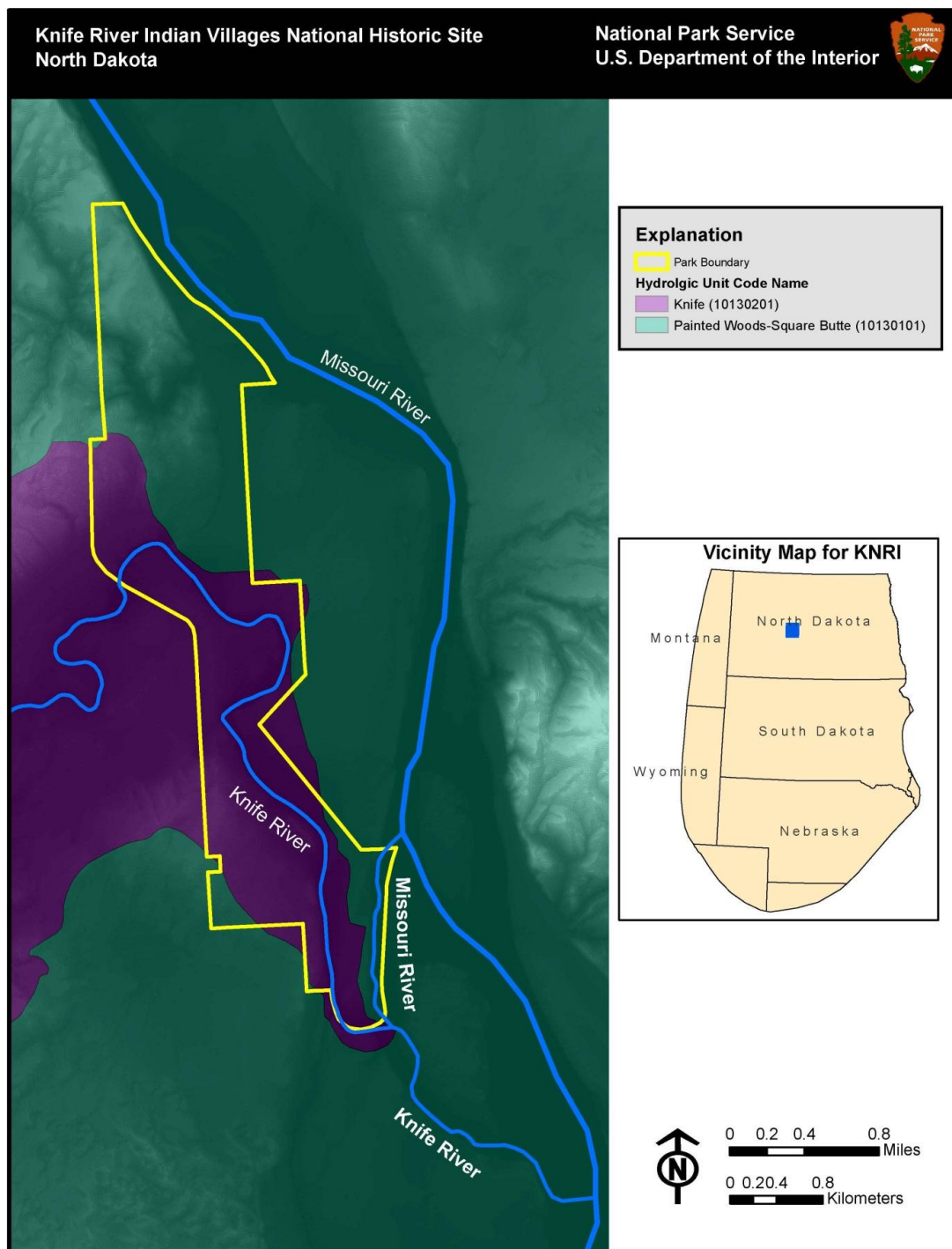


Figure A7. KNRI is located in the Knife and the Painted Woods–Square Butte subbasins (8-digit Hydrologic Unit Codes).

Appendix A. NGPN Hydrologic Unit Code Boundaries (continued).

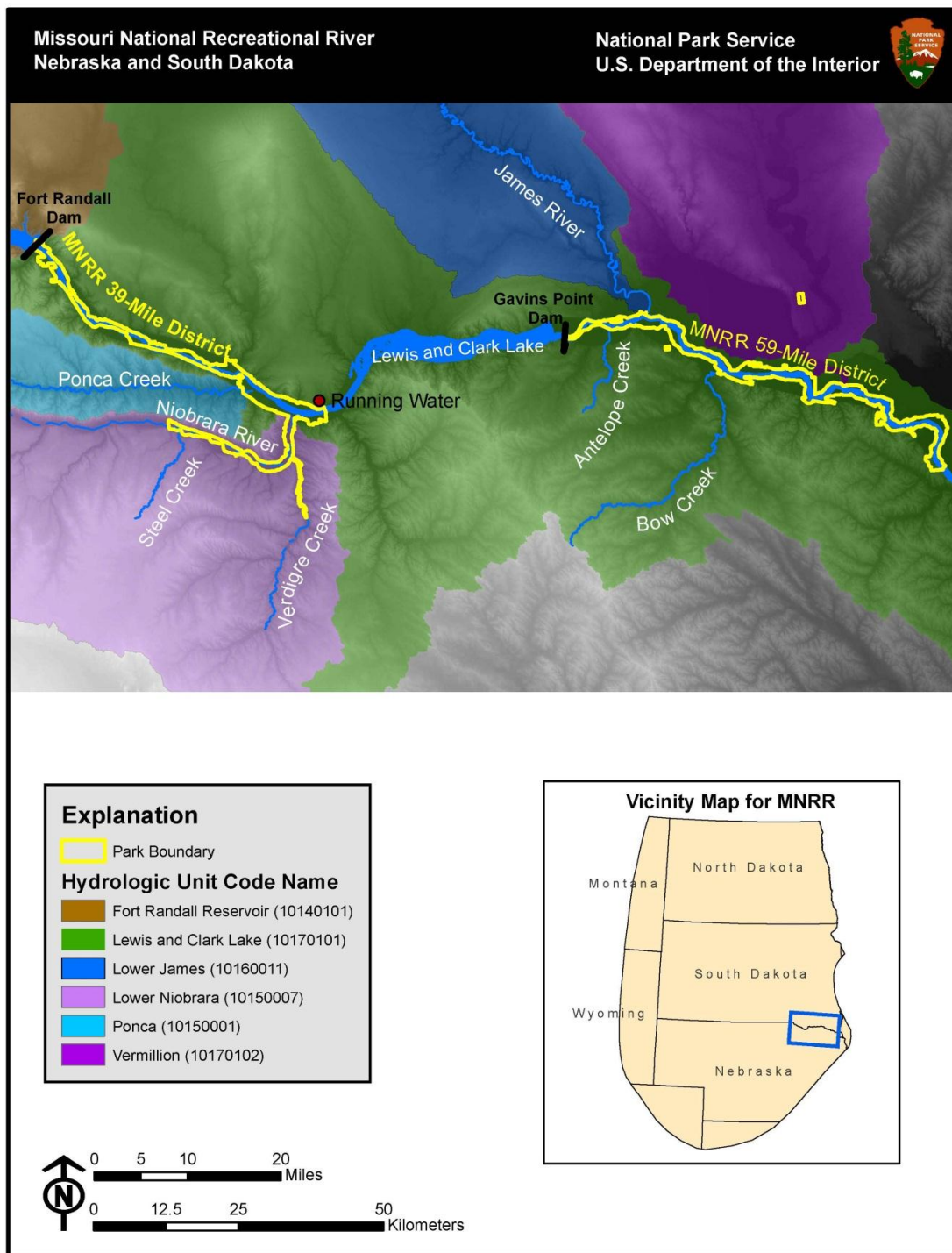


Figure A8. The 39-mile District of MNRR is situated in four subbasins or 8-digit Hydrologic Unit Codes (Fort Randall Reservoir, Lewis and Clark Lake, Ponca, and North Fork Elkhorn). The 59-mile District is located in three subbasins (Lewis and Clark Lake, Lower James, and Vermillion).

Appendix A. NGPN Hydrologic Unit Code Boundaries (continued).

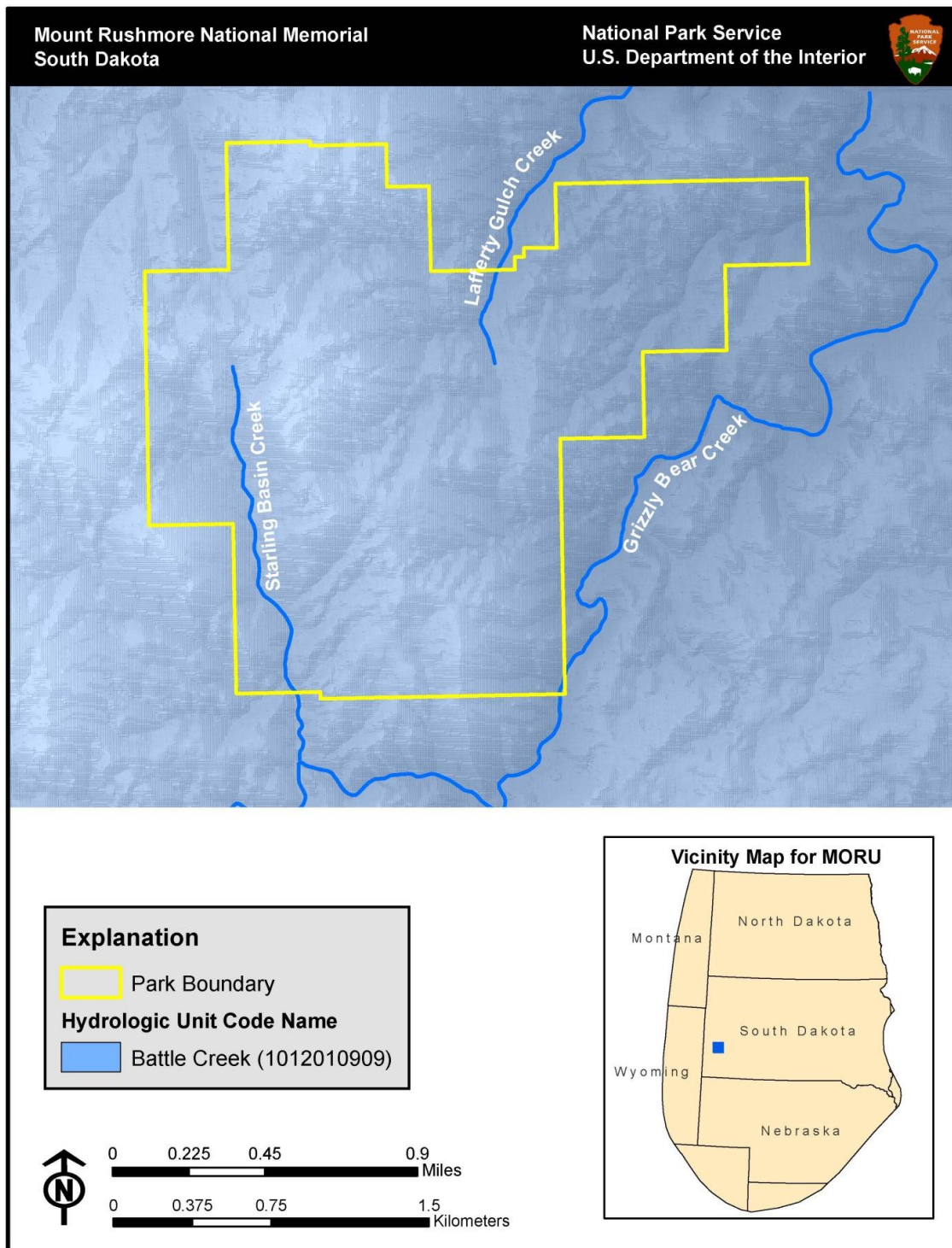


Figure A9. MORU is found in the Battle Creek Watershed (10-digit Hydrologic Unit Code).

Appendix A. NGPN Hydrologic Unit Code Boundaries (continued).

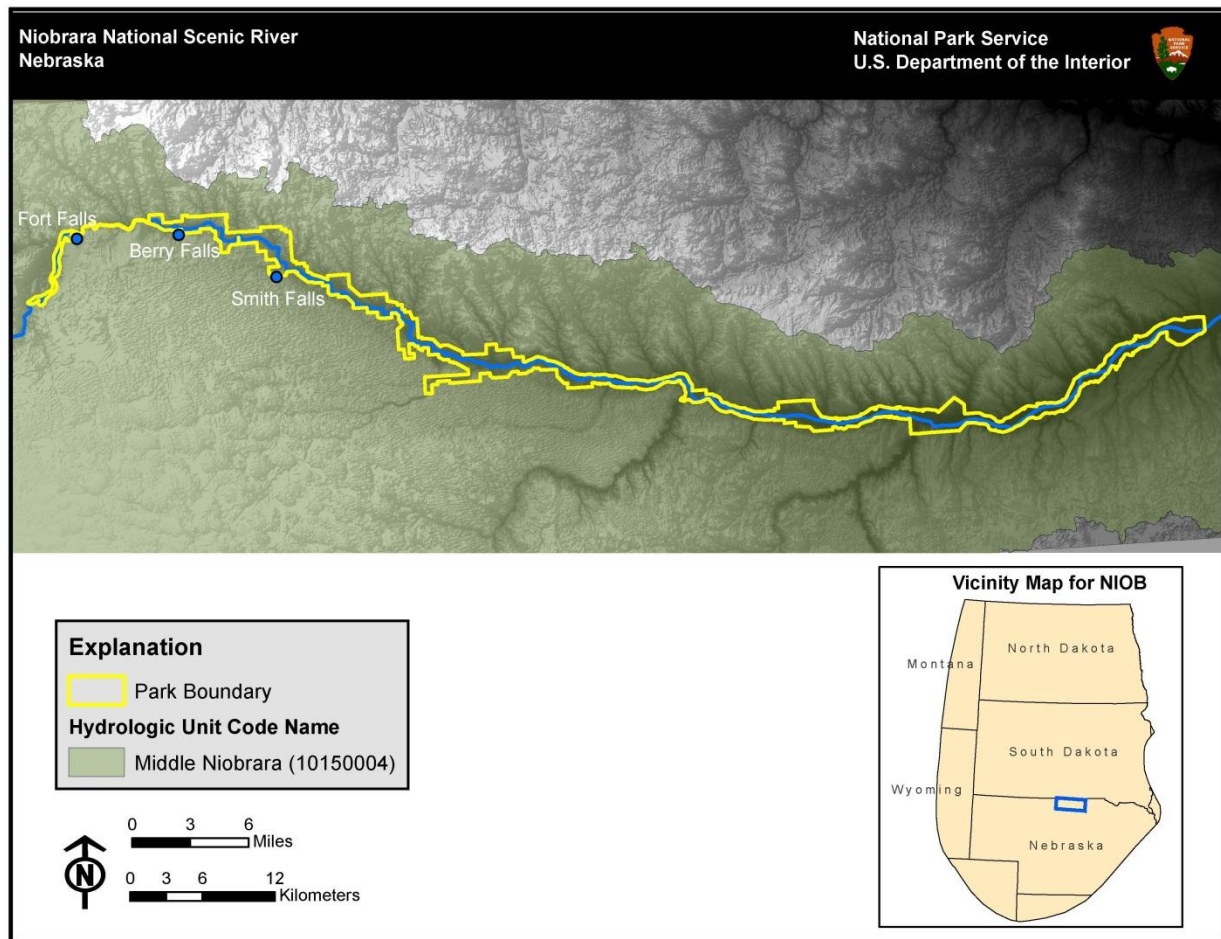


Figure A10. NIOB is located in the Middle Niobrara Subbasin (8-digit Hydrologic Unit Code).

Appendix A. NGPN Hydrologic Unit Code Boundaries (continued).

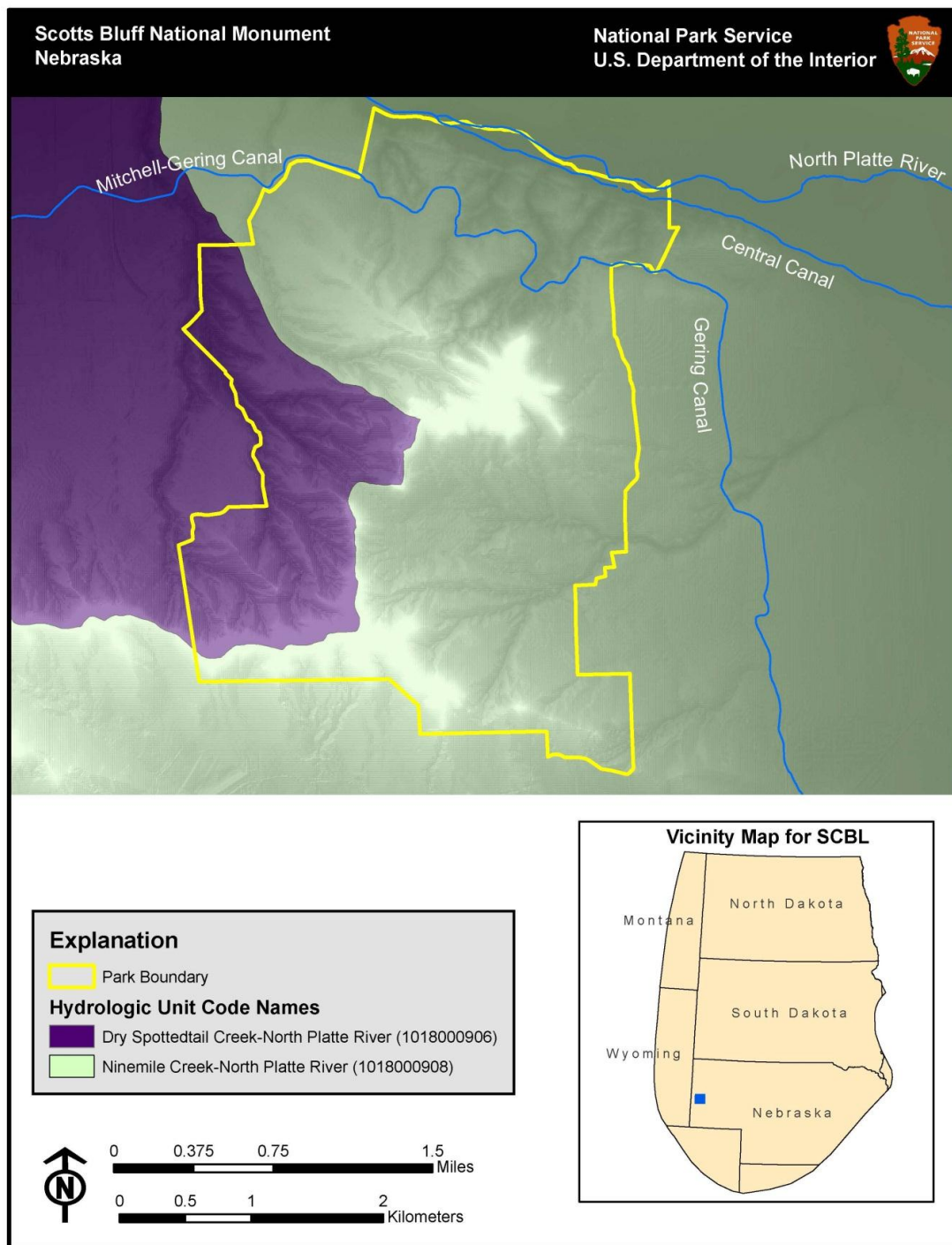


Figure A11. SCBL is situated in the Dry Spottedtail Creek–North Platte River and the Ninemile Creek–North Platte River watersheds (10-digit Hydrologic Unit Codes).

Appendix A. NGPN Hydrologic Unit Code Boundaries (continued).

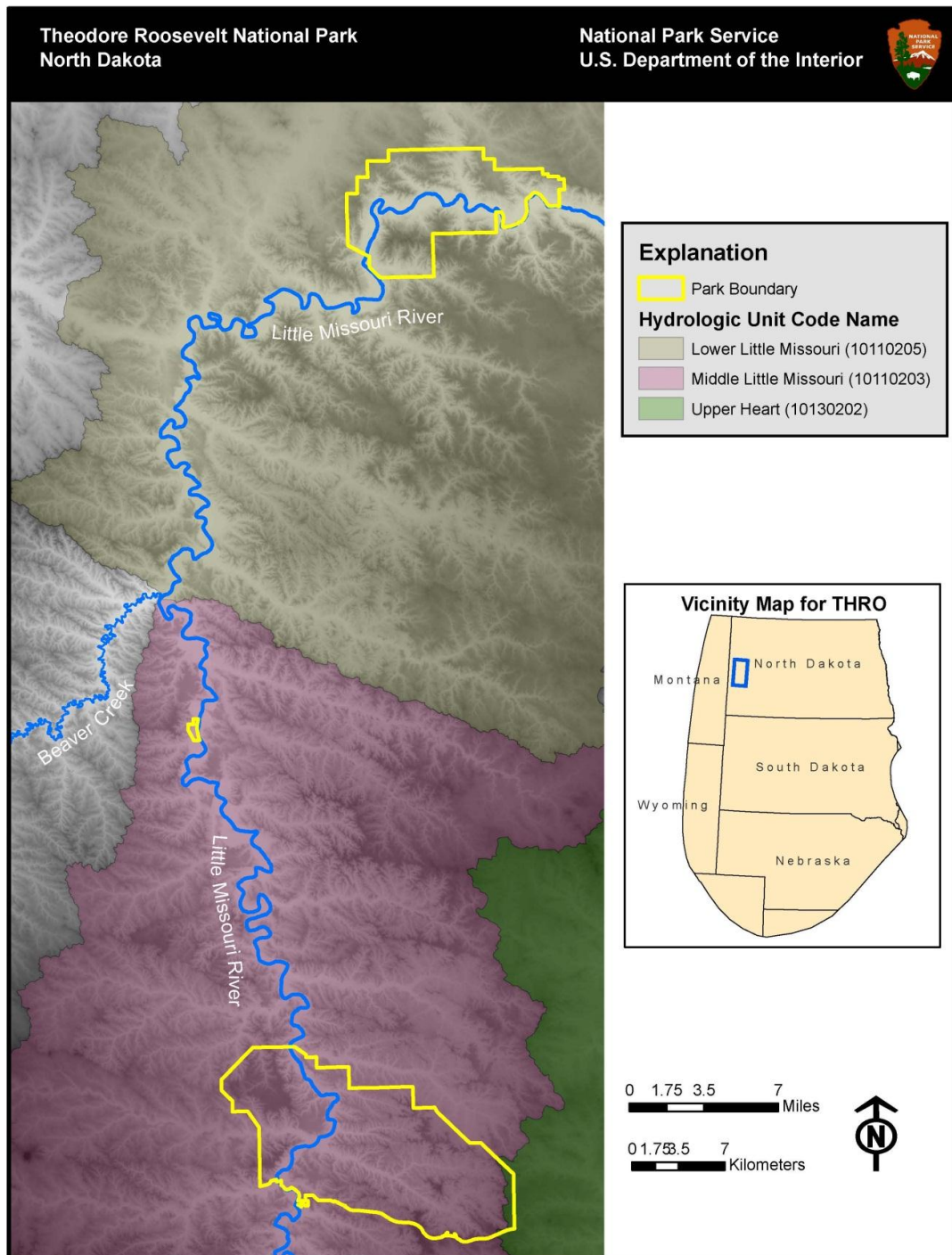


Figure A12. The South Unit of THRO is located in the Middle Little Missouri River and Upper Heart subbasins; the North Unit is found in the Lower Little Missouri Subbasin (8-digit Hydrologic Unit Codes).

Appendix A. NGPN Hydrologic Unit Code Boundaries (continued).

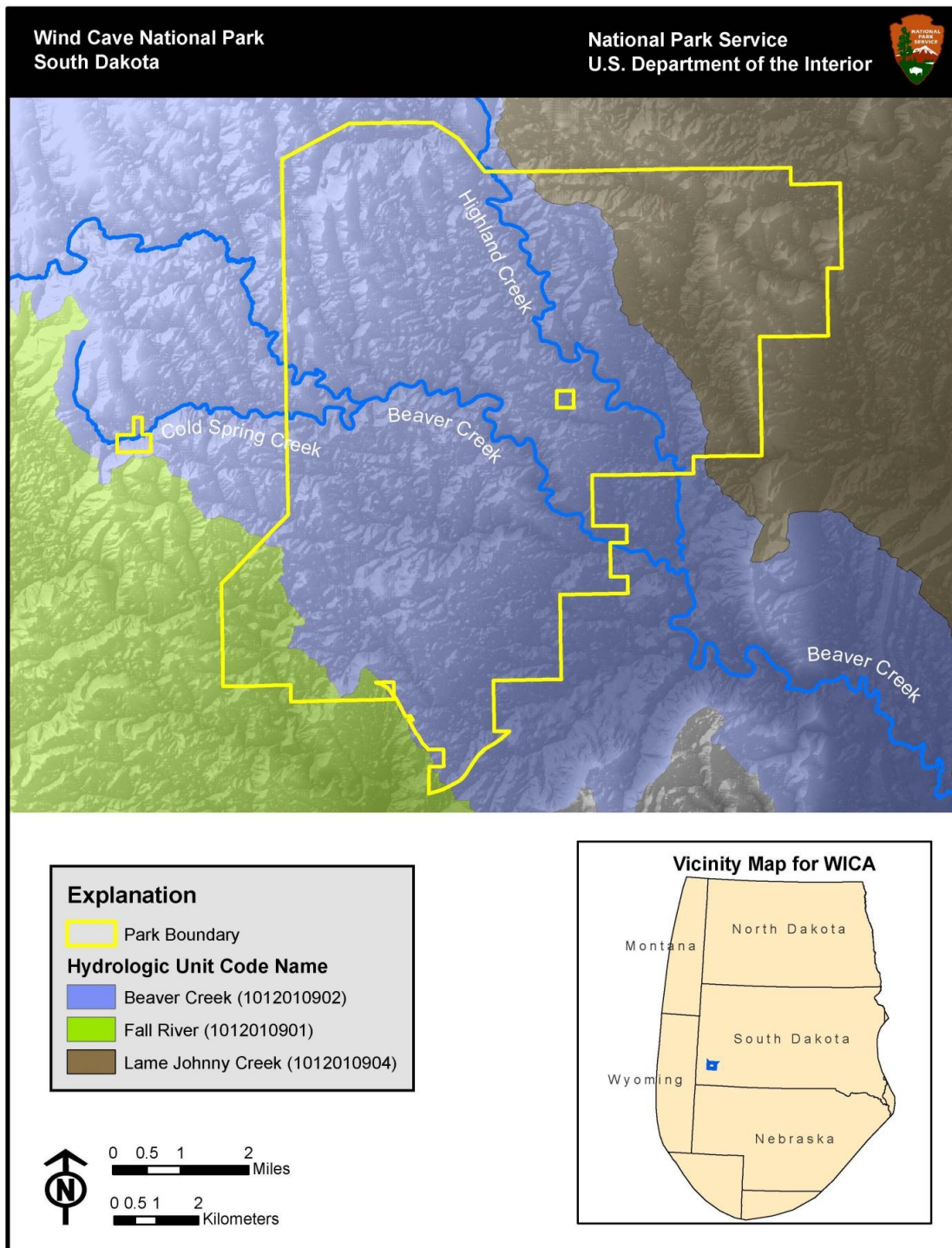


Figure A13. WICA is found in the Beaver Creek, the Fall River, and Lame Johnny Creek watersheds (10-digit Hydrologic Unit Codes).

Appendix B. NGPN Water Quality Sampling Design Examinations

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Power Analysis Framework

I focused on comparing the power of designs to detect a linear trend in a monthly average value for the focal monitoring site(s). The analytical framework was based on the simplifying assumption that trend analysis during operational monitoring would focus on long-term changes in average monthly values and separate analyses would be conducted for each month. In reality, analyses conducted after ongoing monitoring will use a variety of alternative methods (e.g., seasonal Kendall tests) rather than separate analyses for each month; however, assessing power under other methods would require more extensive computer simulations and much more information than we currently have on patterns of within season variability across numerous years.

Trend scenarios and Quantitative Monitoring Objectives

Based on discussions with the NGPN and USGS in 2010–2011, I examined power for two different trend/time horizon scenarios: 2% per year over 10 years, and 1% per year over 25 years. These levels correspond to rapid short-term and gradual long-term changes, relatively speaking. I did not examine power to detect a 2% trend per year beyond 10 years because the scenario of a 2% change per year for >10 years was judged to be too severe to be realistic. For 2% change per year, I report power after 10 years; for 1% change per year, I report expected power after 25 years.

Corresponding to this, for water temperature, DO, and specific conductivity, the assumed quantitative monitoring objectives were to obtain expected power of ≥ 0.80 to detect a 2% per year log-linear trend in the monthly average value(s) for the selected monitoring sites within 10 years, and a 1% per year trend within 25 years, with < 0.10 probability of falsely concluding there is a trend if the true trend is zero.

Variance-component Estimates

A generic variance framework was used to outline relevant variance components, simulate data, and analyze simulated data. The variance framework was tied to a cross-classified additive linear model (e.g., Urquhart et al. 1998; Gray 2012; Urquhart 2012). In the absence of a trend, the model corresponds to the following (Urquhart et al. 1998):

$$y_{\text{year } i, \text{ site } j, \text{ sample time } k} = u + d_i + e_j + f_{i,j} + g_{ijk},$$

where y = an observed measurement on the natural-log scale; u = the overall mean for the park; d_i = a random year effect for year i with corresponding variance component σ_{year}^2 ; e_j = a random site effect for site j with corresponding variance component σ_{site}^2 ; $f_{i,j}$ = an additional random effect for site j in

year i , with corresponding variance component $\sigma_{site \times year}^2$; and g_{ijk} = a random residual term affected by short-term (e.g., within-month) temporal variability and any additional residual measurement error, with associated variance component σ_{index}^2 . Values for each component were taken from estimates on the log-scale using available historic and pilot-study data.

Coherent (park-wide) year-to-year variability (σ_{year}^2): This variance component reflects year-to-year variability consistent across all sites in a park. Estimates of interannual variability were derived based on professional judgment after examining the range of variance estimates produced by exploratory analyses of long-term USGS datasets for the NGPN region.

- For log Temperature, I used estimates of 0.01, 0.05, and 0.10 for σ_{year} (values are presented on the standard-deviation scale, i.e., the square-root of the variance). These values can be interpreted approximately as follows. If we calculate the monthly average for a parameter each year for a single month of interest, these values imply that over many years the standard deviation among the yearly average values for that month would be ~1%, 5%, or 10% of the long-term average temperature (after accounting for any long-term trend).
- For log(dissolved oxygen), values of 0.01 and 0.05 were used for σ_{year}^2 .
- For log(specific conductivity), values of 0.01, 0.05, and 0.15 were used for σ_{year}^2 .

In the absence of continuous long-term monitoring that allows precise estimation of yearly variation, it is unclear which of these yearly variance alternatives are most appropriate for each parameter. Pending availability of consistent long-term data, we are limited to looking at how comparative power of each alternative design changes with these alternative values. Based on analyses of the USGS datasets, however, the highest value specified for each parameter probably is an overestimate of maximum expected yearly variation and represents a worst-case scenario.

Index variability (σ_{index}^2) equaled the sum of expected temporal (diurnal, day-to-day, week-to-week) variability across all 15-minute periods within a month plus residual variability. Although this is a simplistic way of handling complex temporal variability, it appropriately represents the within-site measurement variability for short-term (discrete) visits in which sampling times are not constrained, and either a single measurement or a cross-sectional transect is collected rapidly.

The analyses of 2010 continuous monitoring datasets and examination of within month variability for 2008–2009 continuous monitoring data determined a range of variance estimates for index variability for AGFO, NIOB, and THRO in spring and fall, respectively. For the estimates of residual variability and for spring temporal variability for AGFO and NIOB, estimates were from corresponding park $\times$ season-mixed modeling of 2010 data. When temporal variability could not be estimated in this model or was much lower than corresponding empirical estimates from longitudinal (simple calculations of variability among times), I used the latter. For temporal variability at THRO and for fall at AGFO and NIOB, I compared estimates based on 2010 data with empirical estimates from 2008 (AGFO, NIOB) or 2009 (THRO) continuous monitoring during May–June and Aug–Sept (excluding data >7 days after the last maintenance visit) and used the largest estimate of temporal variability for each

park during each period. Because we wanted estimates of overall within-month temporal variability but only had suitable data for 1–3 weeks each month, using the largest value was justified to minimize underestimation of within-month temporal variation.

Because of the simulation approach used, it was not feasible within the allotted analysis time to separately examine power for every estimated value across the park x season scenarios. Rather, I established values of index variation that covered the range of estimated values for σ_{index} estimated for each of the log-scale parameters for each park x season visit. These values for index variation (values expressed as the square root of the variance) were 0.10 and 0.18 for log (water temperature); 0.10, 0.18, and 0.35 for log (dissolved oxygen); and 0.02, 0.1, and 0.18 for log (specific conductivity). The specific values from these sets relevant to each park x season visits are specified in the results. Note that the values used, although high compared to other sources of variation, were based on continuous pilot data, and are likely to underestimate monthly index variation, as noted above. For each parameter, two or three specified values of index variation were combined with the two or three specified values of yearly variation, and simulations were used to assess power.

Spatial variability (σ_{site}^2): This variance component corresponds to site-specific effects that are consistent across years. The 2010 NGPN pilot study at AGFO, NIOB, and THRO provided estimates of spatial variances expected at each visit. Because all designs involved permanent sampling sites, the magnitude of “longitudinal” (down the stream channel) spatial variation (the square root of the variance; σ_{site}^2) was set to the intermediate level of 0.05 for all parameters, based on 2010 study results. Cross-sectional variability was ignored because estimates of this component based on 2010 data frequently were close to zero.

Site x year variability ($\sigma_{site \times year}^2$): This variance component corresponds to year-specific variation in the true mean for a site each year in addition to variation among sites that is persistent among years and yearly variation common to all sites. No data were available to meaningfully estimate this component because such an estimation would require long-term data from multiple sites also allowing multiple estimates of the monthly mean for each site each year. Assuming a value of zero for this variance component assumed that the true monthly means for all sites paralleled each other exactly across years, an assumption that did not seem plausible based on within-year and diurnal variation in differences among sites observed during continuous monitoring of some NGPN sites during 2008–2010. Instead, I assumed there would be some low level of site x year variation that would cause the within-site correlation of the monthly mean across years to be <1.0. Based on the 2010 pilot study estimates of spatial variation, a value of 0.025, an intermediate-low level of within-visit spatial variation for each log-scale parameters, was selected as an upper bound for expected site x year variation ($\sigma_{site \times year}^2$); however, this variance component was incorporated only into simulation of data during continuous monitoring. For discrete sampling with one to two visits per site per month, the magnitude of index variation was generally much higher than 0.025 (as outlined above), and the specified values for index variation were assumed to already include this variance component.

Designs Evaluated

As described in the NGPN draft water quality protocol, this evaluation focused on two general types of sampling:

Continuous monitoring: as used here, designates that measurements are made at a select site at frequent intervals, (e.g., every 15 minutes) providing a nearly continuous record of water quality during sonde deployment.

Discrete sampling: as used here, refers to a measurement at a select site for a stated number of times during given timeframe.

Based on the NGPN's specified alternatives, I assessed power for the following monitoring designs:

- 1) one site with continuous automated monitoring at short intervals (e.g., every 15 minutes) monitored for 6 months every year;
- 2) one site with continuous monitoring for 6 months every 3 years (i.e. site is monitored in year 1, skipped in years 2 and 3, and revisited in year 4);
- 3) two sites with continuous monitoring for 6 months every 3 years (sites monitored simultaneously; skipped in years 2 and 3, sampled in year 4);
- 4) five sites with discrete sampling two times each month for 6 months every 2 of 3 years (this was not a separate design identified as candidate design by the NGPN, but it was a component of the hybrid continuous/discrete design; therefore, to assess how discrete-only monitoring performed with revisits more frequent than every third year, I extracted separate estimates based on analysis of the "discrete-only" portion of the hybrid design);
- 5) five sites with discrete sampling one time each month for 6 months every 3 years;
- 6) five sites with discrete sampling two times each month for 6 months every 3 years;
- 7) hybrid design, one site with continuous monitoring for 6 months every 3 years and, during the intervening 2 years, five sites with discrete sampling two times each month for 6 months each year; and
- 8) hybrid design, one site with continuous monitoring for 6 months every 3 years and discrete sampling two times each month for 6 months in 2 out of every 3 years (this was not a design specified by the NGPN, but because it essentially is a subset of the previous approach, I calculated and reported power for this design).

Analytical Methods

All simulations and analyses were conducted in program R (R Core Development Team 2010). Power analyses must be tied to a specific analytical method. Perhaps unexpectedly, most of the types of designs considered by the NGPN raise challenging analytical issues:

- For designs #1 and #2 consisting of only a single continuous site, the analytical model was a simple linear regression of the monthly mean for the site versus year. For these designs, the power was calculated analytically (based on, for example, Thogmartin et al. 2007). I also used simulations to double check analytical power estimates and to assess whether the simulated Type I error rate was close to the nominal level (0.10, as specified above). No discrepancies were detected, which is expected given that the simulation approach generated data conforming to the assumptions of the linear-regression hypothesis-testing framework. For many variance scenarios, I also simulated power for these designs assuming that the Kendall-Mann trend test would be used to analyze whether there was a trend in the monthly mean across years for the focal month. These Kendall-Mann results are not presented; power was similar to that calculated analytically based on a linear-regression approach, and the simulated Type I error rate was ≤ 0.10 .
- For design #3 with two continuous sites, the analysis was based on a linear mixed-effects model (fit with REML), with the mean for each site each year as the response variable, site as a fixed effect (given that monitoring sites likely would not be selected randomly), the continuous covariate “year” as a fixed effect (an associated regression “slope” parameter describing the log-linear trend), and the categorical variable “year” as a random effect. The package “nlme” (Pinheiro et al. 2010) was used for all mixed-effects model analyses, with significance of the linear trend coefficient assessed based on conditional t-tests (Pinheiro and Bates 2000). Nominal Type I error rates were ≤ 0.10 .
- I also attempted several other analytical methods for design #3. Results are available but are not summarized here. The Kendall regional test, which essentially combines information about the site-specific trends to assess evidence for a population-wide trend, had Type I error rates much higher than the nominal 0.10, likely driven by the pronounced effect of the specified high coherent year-to-year variation across all sites in the target population, which caused monthly means from the two sites to track each other closely over time. This result was observed with two separate implementations of the Kendall regional test (in R packages “wq” and “Kendall,” respectively). Before using the Kendall regional test for operational analyses of multi-site data from within a single NGPN park, further discussion with experts and possibly simulations will be essential to ensure that nominal Type I error rates are maintained (i.e., that analyses do not have an overly high probability of falsely concluding there is a trend when there is none). Bootstrapping options are available, and this issue is discussed in the water quality trend estimation literature, so these may address the problem; however, incorporating such bootstrap options into the simulations was not feasible with available time. The power obtained with the adjusted Kendall regional test is not expected to have been dramatically better than the methods used in these simplified simulation scenarios.
- A similar but more expected result was observed when design #3 was analyzed with simple analysis of covariance treating site as a categorical variable and year as a numerical covariate. This analysis ignored within-year correlations between the two sites induced by the simulated park-wide yearly effect and had excessive Type I error rates. A Generalized Estimating

Equation approach (GEE) had the same problem; it used only 2 sites and few sampling years and was unable to incorporate a correlation structure (other than the independent correlation structure equivalent to the analysis of covariance approach described above) to account for the fact that each year essentially was a “cluster” of two observations. As a final approach, the average across both sites for each year of sampling was computed, and a Kendall-Mann test on this “park-wide” mean was performed. Nominal Type I error rate with this approach was <0.10 , and observed power was slightly lower (up to 0.10 lower) than the mixed-model approach for which results are reported.

- For discrete-only sampling (designs #4, #5, and #6), I used the same linear mixed-effect model used for the design with two continuous sites, testing for a fixed trend effect with site as a fixed effect (again, assuming nonrandom selection of sites) and year as a random effect. Results would likely have changed little if I instead had treated “site” as a random effect, assuming the NGPN would choose sites probabilistically with this design. The mean measured value for each site in each year was the response variable. Again, nominal Type I error rates were ≤ 0.10 , and a multi-site Kendall regional test had Type I error rates much higher than the nominal 0.10, up to ~ 0.40 when yearly variation was 0.15, and this test was not used further. Again, further discussion with a statistical expert is needed before this analytical approach is used or ruled out for operational analyses once monitoring has commenced; simple adjustments may be available to maintain the desired Type I error rate. Similarly, a GEE approach had excessive type error rates given; during preliminary examinations, I frequently was unable to fit models that incorporated correlation among observations within a year. When using a Kendall-Mann test on the park-wide mean across all five sites for each yearly, monthly mean, I observed Type I error rates lower than the nominal 0.10. However, there were multiple scenarios in which the mixed-effects approach had power slightly higher than 0.80, while the Kendall-Mann analysis of among-site means had power of about ≤ 0.70 , so only mixed-effects power results are reported here.
- The hybrid design #7 is the most problematic in terms of specifying an appropriate analysis method. Two fallback approaches for this design would be to analyze only data from the continuously monitored site or only data from the discrete monitoring. Results applicable to this approach are reported for the “continuous every third year” and “discrete 2 of every 5 years” approaches discussed above. Assuming that the continuously monitored site is also one of the sites used for discrete sampling, another fallback approach would be to utilize data only from this site, for which results are presented applicable to the next design.
- Three analytical approaches were considered that utilized data from both discrete and continuous visits. First, the “park-wide mean was calculated for each year (i.e., the average of continuous measurements for the continuous-monitoring year and the average of the discrete measurements in the other years), and a Kendall-Mann test was performed on these means. The nominal Type I error rate was much lower than 0.10 in most scenarios. Second, a linear mixed-effects model, as described previously, was used, with the mean measured value for each site in each year as the response variable. A concern was that the variance–covariance

structure induced by this hybrid design did not conform to assumptions of the mixed-effects model; however, nominal Type I error rates were <0.10 for most scenarios and no greater than 0.112 for any scenario. For both of these approaches, it was assumed that the continuous site also was used for discrete monitoring as one of the five sites visited during “off” years. If there was no such overlap between the continuous and discrete sites, results might change to an unknown degree.

- The third approach used was a “meta-analysis” approach. A linear-regression estimate of trend and its standard error were calculated from the continuous monitoring only. A mixed-effects model was used for data from the discrete monitoring visits, and the overall trend and its standard error were estimated. A weighted average of the two separate trend estimates was calculated, with each estimate weighted by inverse of its variance. The standard error of this weighted average was calculated (using package “rmeta” in R), and a Wald Z-test was used to assess its significance. Using a t-test based on $n - 1 = 1$ degree of freedom led to extremely low power and Type I error rates $<<0.10$, so this approach was not used. Conversely, the Z-test had simulated Type I error rates of 0.10–0.15 after 10 years of monitoring; therefore, the reported results used an ad hoc adjustment of setting significance for the Wald test to 0.05, which provided a Type I error rate close to the desired 0.10. After 25 years of monitoring, however, the Wald Test Type I error rate was <0.10 when the nominal level was 0.10, and the ad hoc adjustment was not necessary for 25-year results. In contrast to the previous approach, this meta-analysis approach assumed independence of the two separate estimates of trend and therefore was based on a design in which discrete visits to five sites were distinct from the continuously monitored site. Please see the discussion for further cautions about the hybrid design. Consultation with a suitable statistician could identify better options for integrating data from the two components of such a design, but more complex options were beyond the scope of this effort.
- For the hybrid design #8 using only one site, the only analytical method used was to calculate the mean for the site in each year (for the focal month) and perform a Kendall-Mann test on these yearly means for the focal month. Nominal Type I error rates were ≤ 0.10 . I did not attempt to analyze these data with a linear regression approach because of the complex variance–covariance matrix expected for these data, with essentially no sampling variability in years of continuous monitoring and high sampling variability in years of discrete monitoring. If the latter approach had suitable Type I error rates, I expect that power would be similar or perhaps slightly higher than the Kendall-Mann approach. Again, this scenario could be discussed with a statistician to identify or develop alternative analyses.

Simulation Approach

In each scenario, a large number of datasets (5000 for most simulations) were simulated based on specified values of variance components. Separate datasets were generated for each design examined with two exceptions: data used for the discrete-only, 2 out of every 3 years design and the hybrid, one-site-only design were subsets of the datasets generated for the full hybrid design (with five discrete sites).

Each simulated dataset was generated from the cross-classified log-scale additive model similar to that specified above but with an exponential trend on the scale of the raw parameter measurements. Continuous “data” were generated as follows (see also Gray 2012): for each of the m sites monitored in that design, m random site effects (e_j) were generated from a normal distribution with mean zero and standard deviation = σ_{site}^2 ; for each of the n years of monitoring in the simulated park, n random year effects (d_i) were similarly generated but with standard deviation = σ_{year}^2 ; for each site being monitored continuously in a given year, a random site x year effect ($f_{i,j}$) was generated (again from a normal distribution with mean 0 but with standard deviation = $\sigma_{site \times year}^2$).

Therefore, for continuous site j in year i , the simulated monthly mean was:

$$mean(y_{year\ i, site\ j}) = B_o + t * \ln(R) + d_i + e_j + f_{i,j},$$

where B_o = initial log-scale parameter value (set to 1 for all log-scale analyses; this had no impact on results), $R = 1.01$ for a 1% trend and 1.02 for a 2% trend, t = numeric monitoring year (=1 for the first year of monitoring), and other terms are as specified earlier. Because of the high frequency of continuous monitoring within a month, it was assumed that the mean for the site in that year and month was measured without error (i.e., that measurement variability essentially was zero).

For discrete monitoring, site and year effects were generated in the same way, but index variation was incorporated for visit k to site j in year i :

$$y_{year\ i, site\ j} = B_o + t * \log(R) + d_i + e_j + g_{ijk}.$$

The site x year effect was subsumed by the “index” term g_{ijk} . To simulate the mean for site j in year i , the corresponding effect of index variation was simulated by generating a random effect from a normal distribution with mean zero and standard deviation $(\sigma_{index}^2)/v$, where v = number of visits the site that month. This assumed that when a site was visited twice per month, the two observations would be averaged before analysis. For hybrid designs, the same site effect was specified for the continuous site and one of the discrete sampling sites. This design element was ignored for the meta-analytic approach for this design, which assumed that the continuously monitored site and the discrete sampling sites were distinct. Because no variation in trend was modeled across sites and continuous and discrete monitoring was “conducted” in different years, the simulation results for the meta-analytic approach would not change if site effects for all discrete sites were generated independently from the effect for the continuous site.

Each simulated dataset was analyzed with the specified method(s); when multiple analytical approaches were used for the same design, each analysis was applied to the same simulated datasets. Power was determined by calculating the proportion of the simulations for a given scenario for which the analytical method detected a trend (i.e., for which a test of the null hypothesis that the trend coefficient equaled zero produced a p-value less than the specified α -level). In each scenario, 10 and 25 years of monitoring were simulated separately, and power was evaluated after 10 and 25 years. For hybrid scenarios, when the linear mixed effects model analysis failed (e.g., due to model nonconvergence) as indicated by an “lme” error warning (Bates and Maechler 2010), these replicates

were excluded from the calculation of power for this and the meta-analysis approach. This failure was observed in 0 to 5 out of 5000 simulations for hybrid scenarios. To assess Type I error rates for tests of the trend coefficient, data also simulated for and results evaluated as described above for each scenario and analytical method, but with no temporal trend ($R = 1$).

Results

Power results for each parameter, design, trend scenario, and variance scenario indicate that discrete-only designs generally would not meet objectives for detecting a short-term (10-year) change of 2% per year (Tables B1–B3) unless yearly and index variability were low and sites were visited twice per month. With continuous monitoring every third year, a 2% per year, 10-year change likely could be detected if yearly variability was low (0.01), which may be a plausible scenario, particularly for DO, and perhaps for specific conductivity at some parks. Whether or not this magnitude of yearly variability is plausible for water temperature is unknown. When yearly variability was higher, this design had a <50% chance of detecting such a trend, regardless of whether one or two continuous sites were used; however, some analytical methods applied to the hybrid design produced high power to detect a 2% per year, 10-year change if yearly variation was 0.01 or 0.05. As index variability increased, the comparative performance of alternative methods of analyzing data from the hybrid design became somewhat erratic; in some cases, for analysis approaches other than the ad hoc meta-analytic approach, better power was obtained simply by using only data from the continuously monitored site and ignoring the discrete-sampling sites.

For detecting long-term gradual changes (1% per year over 25 years), discrete-only visits every third year would provide sufficient power when yearly variation is not too high and when index variation is moderate to low. For levels of moderate variability, however, two discrete visits per month were needed to obtain desired power. Assuming yearly variation in water temperature is <0.10, which seems plausible based on the range of estimates in continuous monitoring, every third year would provide high power to detect long-term changes, except perhaps for specific conductivity at THRO if it varies highly from year to year. In that scenario with yearly variability of 0.15, however, no design had expected power >0.80 to detect a 25-year, 1% per year change.

Table B1. Power results for water temperature. Shading = designs with power ≥ 0.80 (green) or 0.75 (light green).

2% Trend, Power After 10 Years												
Year Variation	Index (Temporal + Residual) Variation	Park/seasons With Similar Index Variation	Continuous 1 Site Every year (Design 1)	Continuous 1 Site Every Third Year (Design 2)	Continuous 2 Sites Every Third Year (Design 3)	Discrete 5 sites 2 visits/month 2 out of every 3 years (Design 4)	Discrete 5 Sites 1 visit/month Every Third Year (Design 5)	Discrete 5 Sites 2 visits/month Every Third Year (Design 6)	Hybrid: Kendall test on Monthly Park-wide Means (Design 7)	Hybrid: Mixed Model (Design 7)	Hybrid: Meta-analysis (Design 7)	Hybrid: 1 Site Only (Design 8)
0.01	0.10	AGFO Spring/Fall, NIOB Spring	0.99	0.91	0.98	0.89	0.42	0.75	0.98	0.99	1.00	0.83
0.05	0.10	AGFO Spring/Fall, NIOB Spring	0.90	0.47	0.49	0.51	0.30	0.41	0.73	0.82	0.89	0.58
0.10	0.10	AGFO Spring/Fall, NIOB Spring	0.48	0.23	0.23	0.26	0.18	0.22	0.36	0.46	0.55	0.32
0.01	0.18	NIOB Fall, THRO Spring/Fall	0.99	0.91	0.98	0.43	0.11	0.25	0.86	0.71	1.00	0.48
0.05	0.18	NIOB Fall, THRO Spring/Fall	0.90	0.47	0.49	0.32	0.12	0.21	0.62	0.58	0.83	0.35
0.10	0.18	NIOB Fall, THRO Spring/Fall	0.48	0.23	0.23	0.21	0.12	0.17	0.32	0.37	0.52	0.23
1% Trend, Power After 25 Years												
Year Variation	Index Variation	Park/seasons With Similar Index Variation	Continuous 1 Site Every year	Continuous 1 Site Every Third Year	Continuous 2 Sites Every Third Year	Discrete 5 sites 2 visits/month 2 out of every 3 years	Discrete 5 Sites 1 visit/month Every Third Year	Discrete 5 Sites 2 visits/month Every Third Year	Hybrid: Kendall test on Monthly Park-wide Means	Hybrid: Mixed Model	Hybrid: Meta-analysis	Hybrid: 1 Site Only
0.01	0.10	AGFO Spring/Fall, NIOB Spring	0.99	0.99	0.99	1.00	0.98	0.99	1.00	1.00	1.00	1.00
0.05	0.10	AGFO Spring/Fall, NIOB Spring	0.99	0.97	0.99	1.00	0.93	0.97	1.00	1.00	1.00	1.00
0.10	0.10	AGFO Spring/Fall, NIOB Spring	0.96	0.65	0.65	0.79	0.60	0.64	0.93	0.95	0.96	0.89
0.01	0.18	NIOB Fall, THRO Spring/Fall	0.99	0.99	0.99	1.00	0.78	0.97	1.00	1.00	1.00	0.98
0.05	0.18	NIOB Fall, THRO Spring/Fall	0.99	0.97	0.99	0.96	0.68	0.87	1.00	0.99	1.00	0.93
0.10	0.18	NIOB Fall, THRO Spring/Fall	0.96	0.65	0.65	0.74	0.48	0.57	0.91	0.90	0.95	0.78

Table B2. Power results for dissolved oxygen. Shading = designs with power ≥ 0.80 (green) or 0.75 (light green).

2% Trend, Power After 10 Years												
Year Variation	Index (Temporal + Residual) Variation	Park/seasons With Similar Index Variation	Continuous 1 Site Every year	Continuous 1 Site Every Third Year	Continuous 2 Sites Every Third Year	Discrete 5 sites 2 visits/month 2 out of every 3 years	Discrete 5 Sites 1 visit/month Every Third Year	Discrete 5 Sites 2 visits/month Every Third Year	Hybrid: Kendall test on Monthly Park-wide Means	Hybrid: Mixed Model	Hybrid: Meta-analysis	Hybrid: 1 Site Only
0.01	0.10	THRO/NIOB, Spring/Fall	0.99	0.91	0.98	0.89	0.42	0.75	0.98	0.99	1.00	0.91
0.05	0.10	THRO/NIOB, Spring/Fall	0.90	0.47	0.49	0.51	0.30	0.41	0.73	0.82	0.89	0.47
0.01	0.18	AGFO Fall	0.99	0.91	0.98	0.43	0.11	0.25	0.86	0.71	1.00	0.91
0.05	0.18	AGFO Fall	0.90	0.47	0.49	0.32	0.12	0.21	0.62	0.58	0.83	0.48
0.01	0.35	AGFO Spring	0.99	0.91	0.98	0.12	0.03	0.05	0.53	0.25	0.99	0.91
0.05	0.35	AGFO Spring	0.90	0.47	0.49	0.14	0.03	0.06	0.39	0.25	0.76	0.48
1% Trend, Power After 25 Years												
Year Variation	Index Variation	Park/seasons With Similar Index Variation	Continuous 1 Site Every year	Continuous 1 Site Every Third Year	Continuous 2 Sites Every Third Year	Discrete 5 sites 2 visits/month 2 out of every 3 years	Discrete 5 Sites 1 visit/month Every Third Year	Discrete 5 Sites 2 visits/month Every Third Year	Hybrid: Kendall test on Monthly Park-wide Means	Hybrid: Mixed Model	Hybrid: Meta-analysis	Hybrid: 1 Site Only
0.01	0.10	THRO/NIOB, Spring/Fall	0.99	0.99	0.99	1.00	0.98	0.99	1.00	1.00	1.00	1.00
0.05	0.10	THRO/NIOB, Spring/Fall	0.99	0.97	0.99	1.00	0.93	0.97	1.00	1.00	1.00	1.00
0.01	0.18	AGFO Fall	0.99	0.99	0.99	1.00	0.78	0.97	1.00	1.00	1.00	0.98
0.05	0.18	AGFO Fall	0.99	0.97	0.99	0.96	0.68	0.87	1.00	0.99	1.00	0.93
0.01	0.35	AGFO Spring	0.99	0.99	0.99	0.72	0.30	0.51	0.99	0.84	1.00	0.70
0.05	0.35	AGFO Spring	0.99	0.97	0.99	0.67	0.29	0.48	0.96	0.80	1.00	0.62

Table B3. Power results for specific conductivity. Shading = designs with power ≥ 0.80 (green) or 0.75 (light green).

2% Trend, Power After 10 Years												
Year Variation	Index (Temporal + Residual) Variation	Park/seasons With Similar Index Variation	Continuous 1 Site Every year	Continuous 1 Site Every Third Year	Continuous 2 Sites Every Third Year	Discrete 5 sites 2 visits/month 2 out of every 3 years	Discrete 5 Sites 1 visit/month Every Third Year	Discrete 5 Sites 2 visits/month Every Third Year	Hybrid: Kendall test on Monthly Park-wide Means	Hybrid: Mixed Model	Hybrid: Meta-analysis	Hybrid: 1 Site Only
0.01	0.02	AGFO/NIOB, Spring/Fall	0.99	0.91	0.98	1.00	0.99	0.99	1.00	1.00	1.00	1.00
0.05	0.02	AGFO/NIOB, Spring/Fall	0.90	0.47	0.49	0.62	0.54	0.54	0.79	0.93	0.96	0.83
0.15	0.02	AGFO/NIOB, Spring/Fall	0.29	0.16	0.17	0.17	0.16	0.16	0.21	0.29	0.45	0.22
0.01	0.10	THRO Fall	0.99	0.91	0.98	0.89	0.42	0.75	0.98	0.99	1.00	0.83
0.05	0.10	THRO Fall	0.90	0.47	0.49	0.51	0.30	0.41	0.73	0.82	0.93	0.58
0.15	0.10	THRO Fall	0.29	0.16	0.17	0.17	0.15	0.16	0.22	0.29	0.46	0.21
0.01	0.18	THRO Spring	0.99	0.91	0.98	0.43	0.11	0.25	0.86	0.71	1.00	0.48
0.05	0.18	THRO Spring	0.90	0.47	0.49	0.32	0.12	0.21	0.62	0.58	0.90	0.35
0.15	0.18	THRO Spring	0.29	0.16	0.17	0.16	0.11	0.14	0.20	0.25	0.44	0.17
1% Trend, Power After 25 Years												
Year Variation	Index Variation	Park/seasons With Similar Index Variation	Continuous 1 Site Every year	Continuous 1 Site Every Third Year	Continuous 2 Sites Every Third Year	Discrete 5 sites 2 visits/month 2 out of every 3 years	Discrete 5 Sites 1 visit/month Every Third Year	Discrete 5 Sites 2 visits/month Every Third Year	Hybrid: Kendall test on Monthly Park-wide Means	Hybrid: Mixed Model	Hybrid: Meta-analysis	Hybrid: 1 Site Only
0.01	0.02	AGFO/NIOB, Spring/Fall	0.99	0.99	0.99	1.00	0.99	1.00	1.00	1.00	1.00	1.00
0.05	0.02	AGFO/NIOB, Spring/Fall	0.99	0.97	1.00	1.00	0.99	0.99	1.00	1.00	1.00	1.00
0.15	0.02	AGFO/NIOB, Spring/Fall	0.74	0.39	0.57	0.54	0.40	0.40	0.71	0.75	0.78	0.72
0.01	0.10	THRO Fall	0.99	0.99	0.99	1.00	0.98	0.99	1.00	1.00	1.00	1.00
0.05	0.10	THRO Fall	0.99	0.97	1.00	1.00	0.93	0.97	1.00	1.00	1.00	1.00
0.15	0.10	THRO Fall	0.74	0.39	0.57	0.53	0.38	0.41	0.70	0.74	0.77	0.67
0.01	0.18	THRO Spring	0.99	0.99	0.99	1.00	0.78	0.97	1.00	1.00	1.00	0.98
0.05	0.18	THRO Spring	0.99	0.97	1.00	0.96	0.68	0.87	1.00	0.99	1.00	0.93
0.15	0.18	THRO Spring	0.74	0.39	0.57	0.50	0.34	0.36	0.68	0.69	0.76	0.58

Discussion

General role and limitations of power analyses

The NGPN likely will perform a complex mix of analyses on its long-term monitoring data and will be interested in a variety of data summaries and forms of change beyond the focus here on linear changes in monthly averages; however, power/precision examinations must focus on well-defined specific planned analyses and questions. Assessing trends in monthly means likely will be a starting point for operational NGPN analyses, as will assessment of trends in median/minimum/maximum values and other specified percentiles of the monthly distribution of values. Discussions with the NGPN and USGS did not sufficiently specify a variety of other high priority planned analyses or specific forms of change of potential concern to guide additional focused power analyses.

The focus here was therefore on linear trends in monthly means. No power analyses were run for assessing trends in minimum/maximum (min/max) values. A primary purpose of a power analysis is to assess trade-offs and comparative performance of alternative candidate monitoring designs. In the case of the NGPN aquatic monitoring, much of the sampling design uncertainty has been whether to use continuous monitoring, discrete monitoring, or a mixture of the two monitoring types. For that decision, formal power analyses in relation to trends in min/max values is unnecessary; having at least one continuous station is the only way to get meaningful min/max values each month because one to two discrete visits per month cannot capture the full monthly distribution of parameter values. Moreover, for continuous monitoring, power to detect long-term trends in min/max values would primarily be driven by the magnitude of year-to-year variability (along with the number of years elapsed and the yearly revisit frequency), but we have no data for assessing whether yearly variability in min/max values is likely to be much different than yearly variation in mean/median values, for which we have only rough estimates. Therefore, an assumption is that power to detect trends in min/max values would be comparable to results presented here, given that we liberally bracketed the range of plausible yearly variation in means.

Along these lines, the values of plausible yearly variability examined for each parameter produced wide variability in expected power at 10 and 25 years. As noted in the methods, the highest variance value used for each parameter was likely a worst-case scenario, especially given that operational analyses could add covariates that effectively reduce the effect of yearly variation on power for trend detection. Beyond this, we simply have no data at this time for refining these yearly variance estimates to provide a more precise estimate of expected power for various designs. This limitation is a reality of analyses focused on power to detect trend; unless we have rich, long-term datasets relevant to the system being monitored, we will not have accurate estimates of yearly variation (Gray 2012) and cannot precisely estimate absolute power. For guiding protocol choices, the highest value of the results is attained by (a) using the comparative power of alternative designs under optimistic and less-optimistic monitoring scenarios as one of the sources of information used to make initial decisions about the preferred monitoring design, and (b) examining whether the planned monitoring effort has a suitable chance of detecting specified changes of concern.

Power In Relation to Quantitative Monitoring Objectives

Several patterns emerge from this analysis. First, the primary benefit of a design with only discrete sampling one or two times per month every third year would be for potentially detecting long-term gradual changes. Because of the high index variability in most parameters, the discrete-only design would offer little insight into temporal changes during the first decade of monitoring; if index variability is as high as that sometimes observed during 2008–2010 sampling, the power of the discrete-only design may not be high even for detecting a 1% per year, 25-year trend. The relative effect of index variability on a discrete-only design could be reduced if monitoring could feasibly focus on a single part of the diurnal cycle, such as mid-afternoon. If a discrete-only, every-third-year design is the only feasible alternative from a budget standpoint, this sort of approach to reduce the effects of high index variability is recommended to ensure this design has sufficient power to detect even a 25-year gradual change. The approach would require choosing a within-day temporal window of highest importance for capturing changes of concern in water quality as well as logistical planning to ensure sampling occurs during this same window during every visit.

Second, continuous monitoring every third year may detect 2% per year decadal changes if yearly variability is low, such as for DO. Although its ability to meet this monitoring objective under a broad range of scenarios is uncertain, continuous monitoring every three years likely would detect a long-term gradual change under most scenarios.

During the first 10 years of monitoring, the hybrid design could detect a 2% per year change when yearly variance was 0.05, while the continuous-only design could not. Given the low power of discrete-only sampling to detect trends within 10 years, however, the hybrid design likely would offer little insight into variability among sites in trends during the first 10 years; most of the sites monitored would be discrete sites, which would not have sufficient data for assessing differences among sites in temporal patterns within 10 years. Conversely, after 25 years, continuous-only monitoring every third year would have sufficient power in nearly as many scenarios as the hybrid design; however, at that point the hybrid design may have obtained sufficient data on discrete-only sites to provide insights into whether there are differential trends among sites and to assess whether data from the continuous-only site adequately captures broader trends in a park. Concerns about mixing data from discrete-only and continuous-only sites into a single analysis (see below) would be less important because the primary value of the design could be in assessing variability among sites in trends rather than on a unified trend analysis. If an alternative hybrid design in which both discrete and continuous sampling occurred in the same year, every third year, these long-term benefits would be maintained, but there likely would be little extra insight or power from this design within the first decade of monitoring compared to the continuous-only design, given that the revisit frequency would be the same.

Additional Comments about Specific Designs

The comparative advantage of simultaneous continuous monitoring at two sites versus one is not captured in these results. If trends or discrete changes differ within a park due to variation in external stressors (e.g., above versus below a major tributary), even one additional continuous site may offer

critical information, even though power (which was estimated based on a simulation model without variation in trends between sites) would be lower than reported here.

Similarly, these results do not capture some of the trade-offs in monitoring one or two sites continuously versus five sites one or two times per month. With continuous monitoring, events that may be of high importance in structuring riverine systems can be detected, and this monitoring provides data needed to track extremes (monthly min/max values). With continuous monitoring at two or three sites, however, extrapolation from these index sites to other sites depends on the non-statistical assumption that all these sites are showing identical trends. Monitoring a few sites one or two times per month will not provide data for assessing events or min/max values, and in most scenarios has insufficient power to detect trends within 10 years, even if the overall change is 20% after a decade. As monitoring continues past the first decade, however, the discrete-only designs give long-term flexibility for examining whether a consistent trend exists across multiple sites.

Cautions about the Hybrid Design

I strongly emphasize that the hybrid design evaluated is a nonstandard design. The comparative performance of different analytical approaches varied greatly across scenarios and lengths of monitoring and produces additional questions not fully answered by these simulations. For example, the measurement variances for continuous versus discrete years differ greatly; although the linear mixed-effects model still had suitable Type I error rates in these simulations, it is not clear how this issue would interact with other violations of assumptions (e.g., occasionally very high or very low measurements) to effect precision and bias. The meta-analysis approach is an ad hoc approach and required a further ad hoc adjustment to the alpha level to maintain desired Type I error rates after 10 years of monitoring. The design offers additional analytical decisions, particularly whether the site where continuous monitoring occurs also should be used for discrete monitoring, that will affect which estimation methods are suitable. **This design should not be selected and implemented without further discussion with the NPS I&M program-level Quantitative Ecologist or suitable statistician to clear up design and analytical issues.**

More generally, the statistical benefits of supplementing discrete monitoring with infrequent continuous monitoring (e.g., every 10 years) need to be assessed carefully. Periodic continuous monitoring can be invaluable for assessing the “normal” magnitude of variability and extreme events, detecting potential problems, setting thresholds for management concern, and other issues; however, there may be no straightforward way to incorporate this “extra” information in a statistical model to increase power/precision in analyses of discrete monitoring data. This problem should not preclude periodic continuous monitoring; rather, over-optimistic expectations for utilizing such information in formal trend analyses may result unless a clear analytical approach has been outlined.

Statistical Inference from the Designs Examined

The power values reported here must be interpreted carefully. When monitoring sites are chosen purposely rather than randomly, statistical inference applies only to the selected sites, regardless of the number of sites monitored. Statistical models and additional data collection could allow model-based extrapolation but would require high effort. Even with random site selection, if only one or two sites are monitored in a park, then meaningful inference is limited to those sites for all practical

purposes; however, when spatial variability is low and monitoring expensive, there can be high value in assessing trends at a purposely selected site or sites (e.g., weather stations, air quality stations). The determination of the defensibility and value of monitoring NGPN river water quality based on nonrandom site selection is beyond the scope of this report and is up to NPS and USGS water quality experts and NGPN staff.

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NPS 960/127007, October 2014

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