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Protocol Implementation Plan for Cave Water Quality Monitoring in the Northern Great Plains Network, Narrative Version 1.0

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National Park Service
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Natural Resource Stewardship and Science

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ON THIS PAGE
Fluorescein dye in Wind Cave in Windy City Lake, a lake that merged with Calcite Lake before the end of 1999. Dye was injected by National Park Service staff into What the Hell Lake in February 2008 and was detected in Windy City Lake 2 months later. This photograph was taken November 2008 by Peter Sprouse, National Park Service.

ON THE COVER
Upper left: Measuring the physical properties of water from Stairway Spring. Upper right: Leading us to the water in Wind Cave. Photograph by Jason Walz, National Park Service. Lower left: Squeezing through a narrow place above What the Hell Lake in Wind Cave. Photograph by Jason Walz, National Park Service. Lower right: Downloading temperature data collected from Highland Creek. Photograph by Jason Walz, National Park Service.

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Natural Resource Report NPS/NGPN/NRR—2019/1909

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received formal, high-level peer review based on the importance of its content, or its potentially controversial or precedent-setting nature. Peer review was conducted by highly qualified individuals with subject area technical expertise and was overseen by a peer review manager.

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Executive Summary

The Northern Great Plains Inventory and Monitoring Network includes thirteen park units located in five northern Great Plains states across six ecoregions. Two park units, Jewel Cave National Monument (JECA) and Wind Cave National Park (WICA), protect significant cave resources. These two caves are among the longest caves in the world and have an assortment of underground water resources ranging from drip sites to cave lakes. Subsurface water quantity and quality in the caves is a concern due to groundwater depletion and groundwater contamination from pesticides (aboveground applications), hydrocarbons (vehicle use and related activities), and wastewater effluent (sewage systems). Proper monitoring of cave water quality is critical to protecting the resource and preventing it from surface pollution.

The goal of the NGPN Cave Water Quality Protocol Implementation Plan is to determine the current condition and detect changes in select water quality parameters and contaminants in two significant groundwater lakes at both JECA and WICA. In collaboration with the parks, NGPN will monitor cave water quality using methods developed by the United States Geological Survey (USGS) in the National Field Manual. The USGS methods are used to monitor surface and groundwater quality around the nation, and only minor modifications are required to adapt them for cave environments. Water quality samples will be collected from two groundwater lakes once every three years and analyzed by a USGS laboratory for physical characteristics, nutrients, hydrocarbons, and metals. The groundwater lake sites were chosen because they are important park resources, can be accessed reliably, and there is an existing record of water quality data.

Reporting will consist of brief data reports every three years that summarize laboratory results. After nine years, a synthesis report will be completed. At this time, these water quality data can be compared to any other information pertaining to cave water collected by the parks during the same time period. Implementation of this protocol is designed to evolve over time, with a continual evaluation of site selection and water quality parameters to be measured as new cave passages and waterbodies are discovered.

Acknowledgments

Funding for the development of this Protocol Implementation Plan (PIP) was provided by the National Park Service’s (NPS) Inventory and Monitoring Division (IMD); specifically, the Northern Great Plains Network (NGPN). Preliminary scoping for this protocol was completed as part of an interagency agreement between the NPS and the U.S. Geological Survey’s Dakota Water Science Center. In particular, we thank G.C. Delzer and D.A. Bender on their input and assistance of the development of this PIP. The PIP described herein was originally developed by numerous individuals whose peer reviewed and approved work is slightly repurposed for sampling water quality in NPS caves.

Section 1. Introduction

The National Park Service (NPS) established the Inventory & Monitoring Program to facilitate information sharing and natural resource monitoring in national parks. The goal of the program is to gather and analyze information on specific park resources to help parks make sound, science-based decisions. The Northern Great Plains Inventory and Monitoring Network (NGPN), is comprised of 13 NPS park units across Nebraska, Wyoming, North and South Dakota. Two of these units, Jewel Cave National Monument (JECA) and Wind Cave National Park (WICA) protect and preserve large caves in the Black Hills, South Dakota. With more than 200 miles mapped and surveyed, Jewel Cave is recognized as the third longest cave in the world and new passages continue to be discovered (NPS 2018a). Wind Cave contains 150 miles of mapped passages and is known for its unique boxwork formations (NPS 2018b). Wind Cave is also being actively explored and mapped. Both caves contain important water resources. There are several large groundwater lakes, 1500 drip sites, 200 perched pools, and 3 places of constant running water in Wind Cave (Ohms 2016). Jewel Cave contains over 50 drip sites and small pools (NPS 2000, 2007) and several groundwater lakes have recently been discovered (National Parks Traveler 2017).

Cave water quality is an important resource for park managers to understand because it is closely connected to surface water inputs (Gitzen et al. 2010). Models and tracer studies suggest that much of the groundwater in Wind and Jewel caves is sourced from local surface recharge (Long and Valder 2011, Ohms 2016). Subsurface water quantity and quality in the caves is a concern due to groundwater depletion and groundwater pollution from pesticides (aboveground applications), hydrocarbons (vehicle use and related activities), and wastewater effluent (sewage systems) (NPS 2007). There is strong evidence that elevated levels of hydrocarbons, sodium, nitrate, and chlorides in the cave drip water is indicative of surface contamination, often from overlying parking lots (Alexander 1986, NPS 2007). Proper monitoring of cave water quality is critical to protecting the resource and preventing it from surface pollution.

To be successful, consistently applied protocols for the collection and processing of water-quality samples using low-level analytical methods are critical for ensuring that changes detected by water-quality monitoring actually are occurring, are defensible, and not a result of measurements taken by different people or different ways (Oakley et al., 2003). In many cases, the NPS Inventory & Monitoring Program has developed new methods of field data collection and analysis and detailed these in large peer-reviewed monitoring protocols. In other cases, methods are based on established, published protocols from other government or state agencies. A smaller, less detailed Protocol Implementation Plan (PIP) provides information about the published source document and then describes and justifies any differences between the implemented methods and the published source (NPS 2015). This streamlines the publication process and encourages consistency of methods across parks and partners. Cave water quality is an important resource, but it is confined to few parks in NGPN (2 of 13) and to date, JECA and WICA, have been using methods based on the United States Geological Survey National Field Manual (USGS variously dated). Therefore, NGPN has chosen to expedite protocol development by completing a PIP to describe and summarize cave water quality monitoring and any deviations from published source protocols.

NGPN will be adopting the US Geological Survey National Field Manual (NFM) for the Collection of Water Quality Data (USGS, variously dated) with modifications for cave environments and a much reduced scope, due to budget constraints and a confined area of interest. The intent of the NFM is to provide nationally consistent protocols for the collection of water quality data on streams, rivers, groundwater, and aquatic systems in support of national, regional, State, and local information needs, and decisions related to water quality management and policy. The modifications to NFM are listed below. The justifications for each modification is further detailed in Section 4.

1) The NFM focuses on assessing water quality in streams, rivers, and groundwater across the nation using consistent protocols. Here, we focus on groundwater lakes within Jewel and Wind Cave. Lakes are only investigated in smaller numbers across the US, but much like streams above ground, groundwater lakes are known to be indicators of water quality in cave environments and more importantly, they provide a direct link to the underlying aquifer.
2) The NGPN Cave Water Quality Monitoring Protocol focuses on grab samples and the laboratory procedures for water chemistry parameters. In situ field measurements relating to habitat characteristics or hydrology will not be taken. This modification is necessary to protect the pristine water resources in the caves from much human contamination and to meet budget constraints.
3) The NGPN Cave Water Quality Monitoring Protocol focuses only on fixed sites. These sites were not chosen randomly, but rather are chosen because they can be accessed reliable and are unique and important features in the caves.
4) Photographs of the site and sampling procedure will be taken and managed using procedures outlined in the NGPN Water Quality Monitoring Protocol (Wilson and Wilson 2014).
5) Data management procedures will follow standards of the NPS Inventory & Monitoring Network (NPS 2008) and those outlined in the NGPN Data Management Plan (Brumm 2009).
6) Training and safety protocols for accessing caves are added to the NGPN Cave Water Quality Protocol to address significant safety concerns in caves and to reduce the threat of spreading white-nose syndrome.

Section 2. Conceptual Framework for Monitoring

The primary goal of the NGPN Cave Water Quality Monitoring Protocol is to provide information to park managers about cave water quality characteristics. The water in both Wind and Jewel Cave is connected to surface water conditions and runoff (Figure 1). Changes in fire regime, exotic plant management, and visitor use all have the potential to affect water quality. Changes to park infrastructure within and above the cave and changing patterns of visitation in the cave may have large impacts to water quality. The NGPN Cave Water Quality Protocol focuses on anthropogenic contaminants that are particularly problematic for park managers (Table 1).

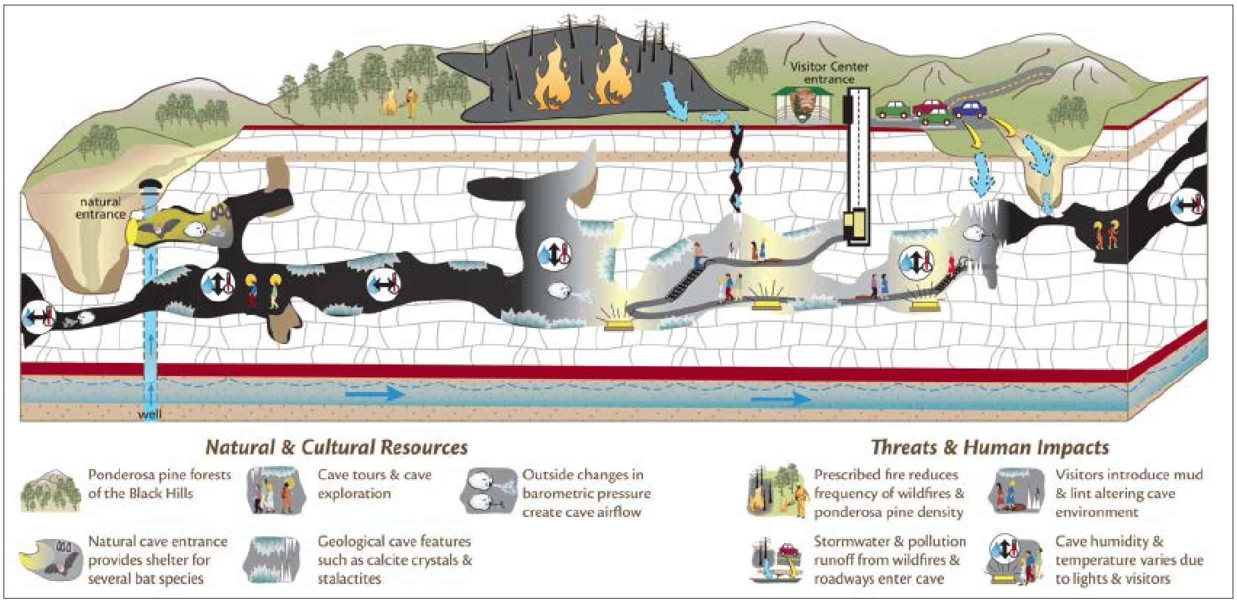

Figure 1. Conceptual diagram of natural and cultural resources and human impacts at Jewel Cave National Monument, which represents similar issues at Wind Cave National Park and other caves in the Black Hills of South Dakota.

Table 1. Factors affecting cave water quality within Jewel and Wind Cave and potential measures for vital sign monitoring. Measures in bold are included in this monitoring protocol.

Management Issue (s) informed by monitoring	Potential water quality measures
Stormwater runoff or spills from parking areas, roads, and holding tanks can change water quality in caves.	Concentrations of chloride, dissolved salts, specific conductance, and other physical constituents in cave water. Concentrations of hydrocarbons, such as toluene and benzene in cave water.
Sewer lines from developments in the park (e.g., housing, visitor center) or surroundings can corrode and leach contaminants into the underlying cave.	Concentrations of nutrients, metals and other organics in cave water. Presence and concentration of *E. coli*.
Changes in climate or above ground features (fire regime) can change timing and amount of surface water inputs to the cave.	Change in rate of infiltration and water levels. Potential for increased concentrations of nutrients, metals, and contaminants over time.
Livestock grazing above the lakes in Jewel Cave can alter water quality.	Concentrations of nutrients and in cave water. Presence and concentration of *E.coli*.
Integrated pest and exotic plant management activities, including pesticide and herbicide use, can contaminate cave water.	Concentrations of pesticides, such as glyphosphate, in cave water.

Section 3. Measurable Objectives

The objectives of the NGPN Cave Monitoring Water Quality Protocol are for a small set of fixed locations at JECA and WICA sampled at a rate of once every three years:

- Determine the current condition and detect changes in select water quality parameters and contaminants in two significant groundwater lakes.

Section 4. What's being Measured and How

NGPN will monitor cave water quality using methods developed by the USGS in the National Field Manual (USGS variously dated). Detailed methods are found in the NGPN Cave Water Quality Protocol Standard Operating Procedures (NGPN 2019). In brief, the steps include:

- Water samples are collected from two groundwater lakes within Jewel and Wind Caves, respectively (Table 2). These locations are fixed sites, two sequential replicates are taken at each site, and sampling is repeated every three years. Because of the unique cave environment and difficulty of access, only trained and park-approved cavers will collect water samples. These will most likely be park staff.
- General notes about the sampling trip will be recorded and photographs will be taken of the water sampling location.
- The samples and field blanks will be removed from the cave and given to USGS collaborators. Sample bottles will be labeled with date, time, and collector name.
- USGS collaborators will have a mobile laboratory near the cave entrance (i.e., a truck in the parking lot), where samples will be filtered (where necessary) and processed for further analyses. USGS will also be responsible for storing and transporting the samples and maintaining chain of custody records.
- Samples will be analyzed in a certified water quality laboratory. As of 2018, this will be the USGS National Water Quality Laboratory in Denver, CO.
- Data will be provided from the collectors (i.e., raw data sheets, photographs) and laboratory (i.e., constituent concentrations) to NGPN where it will be stored, analyzed, and reported on following all IMD data and reporting guidelines.

Table 2. Monitoring objective, sampling methods and variables measured as part of the Cave Water Quality Monitoring Program.

Objective	Sampling Method	Data Collected	Database Tools	Derived Data
Water quality in groundwater lakes	Water grab sample	Laboratory analyses of core inorganic and organic constituents	EQuIS	Concentrations, flagging values above water quality standards and those above historic values

The water samples will be collected using a peristaltic pump system (Figure 2) and the constituents to be monitored (Table 3) include a suite of analytes that may be indicators of contaminants entering the cave system from roads, developments, or changes in land use (Table 1). These constituents were chosen because of their management significance and because there is a historic record from the caves (Heakin 2004, Long et al. 2012, Ohms 2016). The effort required to acquire and process water samples from these groundwater lakes is large and will be completed only once every three years. By including such a large suite of analytes, we will maximize utility of each sample and gain a more thorough understanding of baseline of water quality.

Figure 2. A peristaltic pump being used to collect a water sample in Wind Cave.

Table 3. Core constituents to be monitored in cave water sample in the NGPN Cave Water Quality Monitoring Program. mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter.

Category	Constituent(s)	Reporting level	Units
Physical characteristics	Calcium	0.022	mg/L
	Chloride	0.02	mg/L
	Fluoride	0.01	mg/L
	Iron	10	µg/L
	Magnesium	0.011	mg/L
	Manganese	0.2	µg/L
	pH, laboratory	0.1	pH

Table 3 (continued). Core constituents to be monitored in cave water sample in the NGPN Cave Water Quality Monitoring Program. mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter.

Category	Constituent(s)	Reporting level	Units
Physical characteristics (continued)	Potassium	0.1	mg/L
	Total dissolved solids	20	mg/L
	Silica	0.018	mg/L
	Sodium	0.1	mg/L
	Specific conductance	5	µS/cm
	Sulfate	0.02	mg/L
Nutrients	Nitrogen, ammonia	0.01	mg/L
	nitrogen, nitrite	0.001	mg/L
	nitrogen, nitrite + nitrate	0.01	mg/L
	Total nitrogen, filtered	0.05	mg/L
	Total nitrogen, unfiltered	0.05	mg/L
	Phosphorus	0.003	mg/L
	Orthophosphorous	0.004	mg/L
Metals	Arsenic	0.05	µg/L
	Chromium	0.5	µg/L
	Copper	0.2	µg/L
	Lithium	0.15	µg/L
	Manganese	0.4	µg/L
	Strontium	0.5	µg/L
	Uranium, natural	0.01	µg/L
	Vanadium	0.1	µg/L
	Zinc	2	µg/L
Hydrocarbons	Benzene	0.026	µg/L
	Ethylbenzene	0.036	µg/L
	m- and p-Xylene	0.08	µg/L
	Methyl tert-butyl ether	0.1	µg/L
	o-Xylene	0.032	µg/L
	Toluene	0.05	µg/L

Operational Implementation Notes

- Water quality sampling in a cave environment requires a park-approved trip leader and decontamination procedures must be followed to reduce the spread of white-nose syndrome (National White-nose Syndrome Decontamination Protocol 2018).

The groundwater lakes within the caves should be considered pristine and all human contact should be minimized. In some cases, groundwater lakes cannot be accessed easily because there is no shoreline and climbing down would likely contaminate the water. Therefore, water samples will be taken using a suction-pump method with pre-cleaned Teflon tubing (USGS National Field Manual).

Section 5. Sampling Design and Monitoring Schedule

The primary data for this protocol are subsurface water quality parameters in cave groundwater lakes. NGPN will manage the data according to NGPN Data Management Plan (Brumm 2009) and current Inventory & Monitoring Standards.

The Inventory & Monitoring Division advocates the use of randomized sampling to best understand park resources (Fancy et al. 2009). A traditional randomized approach to sampling cave water in Jewel Cave and Wind Cave is beyond the scope of NGPN and would be very expensive and logistically unfeasible. Moreover, unlike most other NPS resources, these caves are still being actively explored and water sources continue to be discovered. As new passages and water bodies are discovered, any randomized sampling design based on the older area will become incomplete.

Instead of using a randomized sampling design, the NGPN Cave Water Quality Protocol focuses on repeated measures from a few fixed sites (Table 4). These groundwater lake sites were chosen because they are important park resources, can be accessed reliably, and there is an existing record of water quality data. The number of sites is constrained by the budget of this protocol. As of 2018, the $8000 dedicated to water sample analyses will cover the costs of analyzing water for core constituents (e.g., nitrogen, specific conductance) at two site locations per park. This will also cover the costs of ecological or sequential field replicates (2), equipment blanks (1 per trip), and field blanks (1 per trip).

Table 4. Location and rationale for proposed sample sites in Wind Cave National Park and Jewel Cave National Monument.

Park Unit	Water Body	Rationale and Notes
WICA	What the Hell Lake	Past data suggest this lake is connected to Calcite and Windy City. What the Hell is the easiest to access (e.g., 1 hour for experienced caver). Continuous height and temperature data are being collected there.
WICA	Calcite Lake	Connected to Windy City Lake via high water levels. Continuous height and temperature data are being collected there by WICA staff. Moderately easy to access (e.g., 2 hours one-way for experienced caver), however when water levels in What the Hell rise, access to this lake is lost.
JECA	Hourglass Lake	Difficult to access (e.g., 8 hours for experienced caver).
JECA	New Year's Lake	Far from Hourglass Lake and has active infiltration. Difficult to access (e.g., 8 hours for experienced caver).

Groundwater lakes are great integrators of cave water quality because they represent a larger inflow of water and change more slowly over time than compared to the more dynamic cave drip systems. Cave drip systems are closely linked to surface water and to adequately characterize water quality in drips, far more frequent and opportunistic sampling would be necessary to capture dynamics (i.e., after rainfall events). For instance, it was found that water took only eight hours to reach the cave drips from the WICA parking lot in a simulated rainfall event (Heakin 2004). While ideally, both drip water and groundwater lakes could be studied, the Network does not have sufficient funds to adequately monitor drip water. Instead, we focus on groundwater lakes because sampling every three years will provide a more stable and interpretable dataset.

Within a lake, random or stratified sampling locations in deep areas is the preferred method of the NFM (Green et al. 2015). In these groundwater lakes (Table 4), access to the water is limited to only one or two locations. Boats or wading through water to access other areas are not permitted because the park policy is to reduce human contamination of any kind. Therefore, the primary access location for each lake will be used as the sampling location. Two replicate samples will be taken from that location (i.e., sequential field replicate). In the rare case where another access point is possible (or if it is discovered in the future), a water sample will be taken in the secondary site and considered an ecological replicate. To determine and quantify the effect of the potential pump and tubing contamination, blank water (specially prepared distilled and deionized water provided by the USGS laboratory) will be run through the cleaned monitoring equipment used at each park and analyzed in the laboratory (equipment blank). To determine and quantify the effect of field activities (i.e., caving and sample transport), blank water will be transported into the cave and run through the pump, bottled, and treated the same way as the groundwater lake samples (field blank). In total, there will be six water samples analyzed per park (two sequential or ecological replicates per two sites (four samples), one equipment blank, and one field blank)

Because these caves are being actively explored, there may be newly discovered water bodies in future years that would warrant analyses. When and if that happens, the Network, Park Staff, and USGS collaborators may review the fixed locations and revise the sampling location following the appropriate procedures for protocol reviews (Mitchell et al. 2018). Ideally, the new location can be sampled in addition to those sites described in Table 4. However, more often funds will limit this and the tradeoff of new information versus maintaining a historical record will need to be discussed on a case by case basis.

Monitoring will occur on a three-year schedule, starting in 2021, and is dependent upon the availability and amount of funds that can be utilized for sample analyses (Table 5). This sampling schedule is complementary to the NGPN Water Quality Monitoring Protocol for Wadeable Streams and Rivers (Wilson et al. 2014) where water quality is continually monitored at select sites on major streams or rivers in the region. In two years, monitoring is completed at three USGS gauging stations in three national park units and then there is a reduced sampling effort focused on two park units in every third year. This 3-year rotation balances logistic and financial constraints while producing a statistically robust data set (Wilson et al. 2014). Cave water quality will be monitored in the third year of the rotation when there are additional funds available. To reduce the potential for seasonal variation, sampling will be conducted during the summer of each year. Sampling will start in the summer of 2021 and will continue every three years thereafter. Annual sampling could allow for trends to be detected more rapidly and when funds are available from the park or other sources, additional monitoring can be conducted using the same standards that are prescribed in this document.

Table 5. Three year cycle of cave water quality sampling at Wind Cave National Park and Jewel Cave National Monument. An “X” denotes that sampling occurs during that year. Sampling is done every third year when the surface water quality sampling effort in the Northern Great Plains is reduced. Cave water quality sampling will begin in 2021 and continue every three years thereafter.

Park Unit	Water Body	2019	2020	2021	2022	2023	2024
Devils Tower NM	Belle Fourche River	X	–	–	X	–	–
Theodore Roosevelt NP	Little Missouri River	X	–	–	X	–	–
Knife River Indian Villages NHS	Knife River	X	–	–	X	–	–
Agate Fossil Beds NM	Niobrara River	–	X	–	–	X	–
Niobrara NSR	Niobrara River	–	X	–	–	X	–
Missouri NRR	Niobrara River	–	X	–	–	X	–
Missouri NRR	Bow Creek	–	–	X	–	–	X
Fort Laramie NHS	Laramie River	–	–	X	–	–	X
Wind Cave NP	What the Hell and Calcite Lake	–	–	X	–	–	X
Jewel Cave NP	Hourglass and New Year’s Lake	–	–	X	–	–	X

Section 6. Data Management and Reporting

The primary data for this protocol are subsurface water quality parameters in cave groundwater lakes. NGPN will manage the data according to NGPN Data Management Plan (Brumm 2009) and current Inventory & Monitoring Standards (NPS 2008). Data quality standards are listed in Appendix B. Data management and processing handled by USGS personnel and laboratories and will follow USGS methods described in U.S. Geologic Survey NFM (variously dated). USGS will upload these data to the National Water Information System (NWIS) and provide certified data to the NGPN. The field staff will provide raw images and data sheets to the Network. Water quality data will be entered into EarthSoft's EQuIS system, a database and software solution, using the NPS Water Resource Division processing tools. In addition to publishing data to EQuIS, data reports will be produced after each sampling season to summarize field activities and results. More detail is provided in the Data Management, and Data Analysis & Reporting SOP, in brief the NGPN Data Processing and workflow for the NGPN Cave Water Quality Protocol is:

1) All data, including digital copies of supplementary data sheets and digital photographs, will be archived locally on the NGPN Server and will be re-named following Network standards.
2) NGPN will upload the certified data to EQuIS using an electronic data deliverable (EDD) following guidance from NPS Water Resources Division (NPS 2018c). USGS will also add the data to the National Water Information System.
3) Data summary reports will be produced within a year of completion of data collection (i.e., every third year starting in 2022). A trend report will occur less frequently, the first being after three sampling events, or nine years.

Section 7. Budget

The cost the NGPN Cave Water Quality Protocol is approximately $10,000 every three years starting in 2021. These funds will be transferred to the USGS through an Interagency Agreement and cover the costs of equipment, water processing and analytical costs. Table 6 shows the approximate breakdown of funds.

Table 6. Estimated operating costs (based on FY2019 dollars) for implementation of the NGPN Cave Water Quality Protocol. Note these costs are spent once every three years starting in 2021.

Category	Item	Cost	Notes
Personnel	Park staff or cavers (collection of water samples)	$0	In-kind support from WICA and JECA
	NGPN Ecologist	$1,200	~40 hours of GS-11 data summarization, writing, and reporting
	NGPN Data Manager	$300	~10 hours of GS-11 data QA/QC, organization, and transfer to EQuIS
Interagency agreement	Water sample processing	$8,000	Total analytical costs at USGS water laboratory (see Table 3 for constituents)
	Miscellaneous costs of equipment, travel to site	$500	~100 mile roundtrip drive to parks to pick up and process water samples
Total Protocol Implementation Cost per field year	–	**$10,000**	**Costs start in 2021 and every 3 years thereafter**

Section 8. Safety

Collection of water samples within undeveloped caves can involve significant risks to personal safety and health. Due to the extreme risks associated with accessing remote locations in Wind and Jewel Caves, it was determined that Network and USGS staff cannot safely travel into the caves and collect water samples. Rather, **this sampling work must be completed by experienced cavers** and overseen by the cave managers at each park. A park-approved trip leader must be present during all sampling events. Personnel participating in cave activities should be in sound physical condition and have a physical examination annually or in accordance with organizational requirements. To enter the undeveloped portion of the cave, the individual will also be required to attend relevant cave safety trainings and sign forms to acknowledge and understand the risks associated with caving. Personnel should also be familiar with park specific cave rescue pre-plans.

A Job Hazard Analysis form for working in cave environment which is available in Appendix A, covers required equipment and tools, required safety equipment, potential hazards, and safety procedures for working in a cave environment. Specific concerns and guidelines include:

- Wear helmets at all times.

- Each group must have an adequate first aid kit and/or knowledge of the location of in-cave rescue caches.
- Each person will have at least three independent light sources when in the cave.
- Trash and human waste will be removed from the cave.
- Trip leaders must properly plan trips to maximize efficiency and productivity while ensuring the safety of group members at all times.
- Pre and post-trip safety briefings are required.

The water sampling should involve minimum risks because the sampler should come in limited contact with the water. Although unlikely, toxic substances that can be absorbed through the skin or inhaled may be present in the water. For each site, know the location of the nearest emergency care facility. If there is an environmental incident, the following emergency telephone numbers should be provided to all field crews: State or Tribal department of environmental quality or protection, U.S. Coast Guard, and the U.S. EPA regional office. In the event of a major environmental incident, the National Response Center may need to be notified at 1-800-424-8802.

Section 9. Standard Operating Procedures and Deviations from Source Protocols

To ensure consistent implementation of the NGPN Cave Water Quality Protocol over time, the Standard Operating Procedures (SOPs) list in Table 7 have been developed or identified. The main source of the SOPS is the US Geological Survey National Field Manual (NFM) for the Collection of Water Quality Data (USGS, variously dated). Other SOPS have been adopted for training and reducing the spread of white-nose syndrome. Data management, reporting, and protocol review SOPS have been adopted from Inventory & Monitoring Division guidelines and the standard operating procedures of the NGPN Water Quality Monitoring Protocol (Wilson and Wilson 2014).

Table 7. Standard Operating Procedures required for the Northern Great Plain Network Cave Water Quality Monitoring Protocol. The SOPS are available at NGPN 2019.

Topic	Source Protocol	Explanation of Primary Differences	Link to Published Document / IRMA record
1. Preseason Preparations for Water Sampling	U.S. Geological Survey, National Field Manual for the Collection of Water Quality Data: Chap 1 Preparations for water sampling (Wilde 2005)	This SOP outlines preparations that are necessary for collecting water samples (e.g., site reconnaissance, ordering supplies). The standard SOP is revised for Cave Water Quality Monitoring (CWM) to include different data management procedures for NPS samples and local site specific information. There is also added information about preseason meetings and reviewing the terms of the Interagency Agreement.	https://water.usgs.gov/owq/FieldManual/chapter1/Ch1_contents.html
2. Training Field Personnel	Jewel Cave NM Cave and Karst Management Plan: Environmental Assessment (NPS 2007)	The SOP outlines training requirements for conducting work in off-trail area areas of Jewel Cave NM. The standards for CWM are expanded to include Wind Cave NP. Special trainings requirements for water sampling are also included.	https://irma.nps.gov/DataStore/Reference/Profile/2248429
3. White Nose Syndrome Decontamination Procedures	US National White-nose Syndrome Decontamination Protocol (USFWS 2018)	The SOP outlines requirements for reducing the spread of White Nose Syndrome while conducting work in caves. The only minor modification for CWM is that water sampling equipment is not shared between Jewel and Wind Cave.	https://www.whitenosesyndrome.org/mmedia-education/united-states-national-white-nose-syndrome-decontamination-protocol-april-2016-2
4. Establishing and Navigating to Cave Site Locations	Jewel Cave NM Cave and Karst Management Plan: Environmental Assessment (NPS 2007)	This SOP describes the procedures for establishing marked locations within Jewel Cave. The CWM SOP standards are expanded to include Wind Cave NP.	https://irma.nps.gov/DataStore/Reference/Profile/2248429

Table 7 (continued). Standard Operating Procedures required for the Northern Great Plain Network Cave Water Quality Monitoring Protocol.

Topic	Source Protocol	Explanation of Primary Differences	Link to Published Document / IRMA record
5. Sample Design & Monitoring Schedule	Water Quality Monitoring Protocol for Wadeable Streams and Rivers in the Northern Great Plains Network: Standard operating procedures (Wilson and Wilson 2014)	This SOP describes the 3-year sampling cycle and the location of fixed monitoring sites in WICA and JECA. The additions to this SOP include the rationale and description of the fixed sites chosen for Cave Water Quality Monitoring.	https://irma.nps.gov/DataStore/Reference/Profile/2216800
6. Water Sample Collection	U.S. Geological Survey, National Field Manual for the Collection of Water Quality Data: Chap 4 Collection of water samples (USGS 2006)	This SOP describes how to collect water samples for laboratory analyses of chemical constituents. The CWM SOP clarifies that the preferred method in groundwater lakes is the suction-lift pump.	https://water.usgs.gov/owq/FieldManual/chapter4/html/Ch4_contents.html
7. Water Sample Processing	U.S. Geological Survey, National Field Manual for the Collection of Water Quality Data: Chap 5 Processing of water samples (Wilde et al. 2004)	This SOP describes how to process water samples for laboratory analyses of chemical constituents. The SOP clarifies that USGS personnel will assist with the processing of samples and identifies the laboratory being used for analyses for CWM.	https://water.usgs.gov/owq/FieldManual/chapter5/html/Ch5_contents.html
8. Photographic Documentation	Water Quality Monitoring Protocol for Wadeable Streams and Rivers in the Northern Great Plains Network: Standard operating procedures (Wilson and Wilson 2014)	This SOP describes the how to properly take and manage photographic data. The CWM version uses different codes to specify that it is part of the Cave monitoring program.	https://irma.nps.gov/DataStore/Reference/Profile/2216800
9. Postseason Procedures	Water Quality Monitoring Protocol for Wadeable Streams and Rivers in the Northern Great Plains Network: Standard operating procedures (Wilson and Wilson 2014)	This SOP describes procedures for debriefing and season reviews. The CWM version highlights the need to communicate with park and USGS collaborators.	https://irma.nps.gov/DataStore/Reference/Profile/2216800
10. Data Management	Water Quality Monitoring Protocol for Wadeable Streams and Rivers in the Northern Great Plains Network: Standard operating procedures ((Wilson and Wilson 2014)	This SOP describes the data management procedures for NGPN water quality data. The CVM version differs because the data are not continuous and data will be uploaded to EQuIS using the NPS WQX Electronic Data Deliverable.	https://irma.nps.gov/DataStore/Reference/Profile/2216800

Table 7 (continued). Standard Operating Procedures required for the Northern Great Plain Network Cave Water Quality Monitoring Protocol.

Topic	Source Protocol	Explanation of Primary Differences	Link to Published Document / IRMA record
11. Data Analysis and Reporting	Water Quality Monitoring Protocol for Wadeable Streams and Rivers in the Northern Great Plains Network: Standard operating procedures (Wilson and Wilson 2014)	This SOP describes the summary data analyses and reporting schedule. The CVM outlines specific considerations for this protocol including, the area of inference is limited to the fixed sites (groundwater lakes) and larger summary reports will be completed after 3 rounds of sampling.	https://irma.nps.gov/DataStore/Reference/Profile/2216800
12. Protocol Revisions	IMD Protocol Review Guidance	This SOP describes how to review and revise NPS monitoring protocols. The CWM version clarifies that operational reviews will be done in concert with the 3-year sampling cycle, instead of annually.	https://irma.nps.gov/DataStore/Reference/Profile/2253227

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Appendix A. Job Hazard Analysis (JHA) Form for Off-Trail Caving

<table>
<tr><td colspan="4">Jewel Cave National Monument JOB HAZARD ANALYSIS</td></tr>
<tr><td colspan="3">Job Description:
Caving (off-trail)</td><td>Date of last update:
February 9, 2012</td></tr>
<tr><td>Division with primary responsibility for this JHA:
Resource Management</td><td>Last updated by:
D. Austin</td><td>Reviewed by:</td><td>Approved by:</td></tr>
<tr><td>Required standards & general notes:</td><td colspan="3">Cave entry permits must be obtained and approved prior to any caving activity. Trip leaders must be appropriately trained and prepared for the type of trip they are leading. Each team member must be prepared for the type of trip and familiar with rescue pack locations along the nearest travel route. Surface contacts must also be established prior to the trip. All PPE will be inspected and tested prior to using, and all equipment will be adequate for the type of trip.</td></tr>
<tr><td>Required personal protective equipment:</td><td colspan="3">UIAA approved helmet with four-point suspension chin strap, three reliable independent light sources, knee-pads, elbow-pads, gloves, treaded boots with good soles and ankle support</td></tr>
<tr><td>Typical tools & equipment:</td><td colspan="3">Side-mounted pack, adequate drinking water, adequate quick-energy food supply, extra batteries, watch, cave maps</td></tr>
</table>

Activity	Potential Hazards	Safe Action or Procedure
Planning Cave Trip	Lack of leadership and communication. Planning a caving trip that will exceed the abilities of any team member. These abilities include physical condition, technical skills and psychological aspects.	One person for each trip will be designated as the trip leader. This person is responsible for providing leadership and clear communication concerning safety, minimizing impact to the cave resource and achieving the trip goals. Ensure that trip plans are within the range of all team members. Discuss trip plans with team members and make sure each member understands the trip plans, is prepared to meet the challenges of the trip in terms of physical condition, technical skills and psychological aspects.
Preparing Equipment	Not bringing proper equipment to achieve the planned objectives.	Trip members will make sure they have the proper personal equipment for the trip. Trip leader will ensure that all group equipment is properly prepared.
	Equipment worn, broken or inoperable due to lack of proper maintenance.	Each trip member is responsible for regularly checking, cleaning and ensuring that all caving equipment is in proper working order.
	Team member not knowing how to properly use caving equipment.	All team members will have the training and knowledge as to proper usage of each piece of equipment used for their specific trip.
Horizontal Caving (general)	Exposed climbs	Always use three points of body contact on cave surfaces to minimize risk of falling. Where feasible, use a hand-line or belay
	Slippery surfaces / Falling	Everyone will wear footwear with good traction and a caving helmet with a chinstrap. Everyone should move in a careful, controlled manner to avoid falling. When climbing, test all holds to ensure that they can withstand the force being placed upon them.
	Tight squeezes	Prepare the team before the trip by having everyone squeeze through the concrete block on the covered patio. Describe the specific tight spots that will be encountered during a trip, and ensure everyone can fit.

Activity	Potential Hazards	Safe Action or Procedure
Horizontal Caving (general)	Becoming lost / disoriented, complex mazes	Trip leaders should obtain cave maps for everyone on the team, and prior to the trip should study the intended route and identify hazards or obstacles. Trip leaders should also describe the flagging trail system and how to navigate by using both the flagged trails and visible survey stations. The team should stick to the planned route at all times.
	Possible temperature related issues due to the 49-50 degree temp and near 100% humidity	Ensure team members are appropriately dressed for continued movement – a short-sleeved shirt and lightweight, durable pants are usually sufficient and prevent overheating. Ensure team members have adequate cold-weather clothing in their packs such as a balaclava and long-sleeved polypro shirt. Explain to team members about the colder temps while not moving and the necessity of wearing these items to prevent hypothermia.
	Exertion / Exhaustion	Each team member should have adequate knowledge of the length and duration of trip prior to heading into the cave, and should have cave-specific physical conditioning. Each team member should be briefed on how much quick-energy food and water will be necessary to keep up with calorie utilization during the trip. Prior to the trip, the trip leader should inquire about people with known physical conditions and treatment needs. Groups should avoid overexertion, and should stop at least every hour to eat and drink. Group speed should be tailored to the slowest person on the team. Should the trip become too much for one trip member, the whole trip plan will be modified to achieve a safe trip.
	Overdue party	Trip leaders should always establish a surface watch prior to embarking on a trip. This person should be briefed on what time to expect the team to return and who to contact in the event the team does not exit on time. Location of the team, number of participants and travel route maps will be readily available on the surface (cave locker). A hasty team will be established prior to the trip to assess any situation if the need arises. Trip leaders will allow a reasonable amount of time for the team to exit the cave.
	Dehydration	All team members will be properly hydrated before entering the cave and drink sufficient water during the trip to maintain a proper hydration.
	Rock fall	Cavers should locate themselves in places where they will not be exposed to rockfall from team members above them. Cavers will move carefully and thoughtfully so as not to knock rocks down on those below them. Should a team member accidentally knock down a rock that team member will clearly yell "Rock!" to inform those below of the impending danger. All team members will wear a caving helmet with a chinstrap. This helmet should not be removed when in an area with a potential for rockfall.

Activity	Potential Hazards	Safe Action or Procedure
Single Rope Technique	Miscommunication resulting in someone entering the rockfall zone while another team member is still in a position to knock rocks down or while another team member is still on rope.	Clear signals will be used to avoid miscommunications. "On Rope" will be clearly shouted when entering the rockfall zone with the intent to rappel or ascend a rope. "Off Rope" will be clearly shouted after getting off rope and exiting the rockfall zone. A clearly shouted "OK" from the other team members should acknowledge either of these commands.
	Ropes and or rigging materials worn or damaged.	All ropes and rigging materials will be inspected for wear or damage before use. If necessary damaged or worn materials will be retired.
	Unsafe Rigging.	All rigging will be inspected before use to ensure that it is safe. If determined not to be safe, the rigging will be modified if possible or the trip halted until the rigging can be made safe.
	Rope damage encountered while on rope.	A butterfly knot will be used to eliminate the damaged section of rope from the life supporting rope. A note will be left both at the top and bottom of the rope informing cavers of the situation.
	Incident occurs where caver is forced to change over to ascent while descending or to descent while ascending.	Everyone participating in SRT will be required to have the equipment, training and knowledge to perform changeovers from ascent to descent and descent to ascent.
	Object becomes jammed in rappel device.	Everyone participating in SRT will be required to have the equipment, training and knowledge to safely lock off their rappel device and remove the jammed object without using a knife.
	Difficulty in passing a rebelay, traverse or other complex rigging situation.	All persons traveling to sections of cave with complex riggings will be required to have the equipment, training and knowledge to safely negotiate these complex riggings.
	Caver becomes exhausted, unconscious or injured resulting in immobilization on rope.	When someone becomes immobilized on rope, it is critical to remove that person from rope as soon as possible. Although not a requirement, ideally every trip should have at least one person capable of performing a pick-off.

Appendix B. Data Quality Standards for the NGPN Cave Water Quality Monitoring Protocol

Overview

The Northern Great Plains Inventory and Monitoring Network (NGPN) includes thirteen park units located in five northern Great Plains states across six ecoregions. Cave water quality monitoring occurs in two park units with cave and water resources, Jewel Cave National Monument and Wind Cave National Park. These two caves are among the longest caves in the world and have an assortment of underground water resources ranging from drip sites to cave lakes. Subsurface water quantity and quality in the caves is a concern due to groundwater depletion and groundwater pollution from pesticides (aboveground applications), hydrocarbons (vehicle use and related activities), and wastewater effluent (sewage systems). The NGPN Cave Water Quality Monitoring Protocol is small in scope and focuses on the collection of water samples from two fixed sites (groundwater lakes) in both caves, every three years. The location for sampling within each groundwater lake is limited by access within the cave (there is currently only one access location per lake). The water samples are collected by park staff and processed by the USGS South Dakota Water Science Center with funding through an interagency agreement. Water samples are analyzed for a select set of nutrients, trace metals, physical properties, and contaminants.

The objectives of the Cave Monitoring Water Quality Protocol are for a small set of fixed locations at Jewel Cave National Monument and Wind Cave National Park:

- Determine the current condition and detect changes in select water quality parameters and contaminants in two significant groundwater lakes.

Protocol Activities and Modules

Data are collected or derived as a part of the Northern Great Plains Network Cave Water Quality Protocol in three different activities or modules: site establishment (where applicable); field observations, and lab sample data (Table B1).

Table B1. Project activity matrix for Monitoring Cave Water Quality in Northern Great Plains Network.

Category	Activity Number	Activity	Description
Field Observations	1	General Field Notes	Field notes from the cave trip leader, including location of lake, time to access sites, time and data of water sample, type of collection, and trip members.
Sensor Data	2	Photopoint data	Photos taken of water collection location taken. These are taken from a known location based on detailed written description and past photographs (locations within the cave will not be permanently marked). Photographs taken of the trip to and from water sampling locations.

Table B1 (continued). Project activity matrix for Monitoring Cave Water Quality in Northern Great Plains Network.

Category	Activity Number	Activity	Description
Field Sample Collection and Processing	3	Water Quality samples	Water samples collected from 2 groundwater lakes within the cave and provided to the USGS for processing.
	4	Water Quality sequential replicate samples	Sequential replicate water samples collected from each of the 2 groundwater lakes and provided to the USGS for processing. In rare cases where the groundwater lake is accessible in more than one location, the replicate may be taken in another location in the water body (ecological replicate)
Laboratory Data	5	Water quality parameters – nutrients	Water grab samples for laboratory analysis of nutrients
	6	Water quality parameters – physical characteristics	Water grab samples for laboratory analysis of physical characteristics
	7	Water quality parameters – metals	Water grab samples for laboratory analysis of metals
	8	Water quality parameters – hydrocarbons	Water grab samples for laboratory analysis of hydrocarbons
Quality Control Data	9	Equipment blank	Blank water is run through the pump and any associated equipment prior to deployment and then sent to the laboratory for the same analyses as the water samples (activity 5-9). This tests for equipment contamination.
	10	Field blank	Blank water is brought into the cave, run through the pump, and then treated as all other samples. The field blanks are then sent to the laboratory for the same analyses as the water samples (activity 5-9). This tests for equipment and handling contamination.

Sampling Design

The Cave Water Quality Monitoring Protocol involves the collection of water samples for laboratory analyses of chemical constituents from two groundwater lakes in both Jewel and Wind caves. The type of monitoring activities and sample designs are described in Table B2. The location of sampling within a groundwater lake will be the primary (most often only) access point within the cave. This is a targeted design with a revisit schedule of every three years, starting in 2021.

Table B1. Activity-level sample design matrix for Cave Water Quality Monitoring Protocol.

Category	Activity Number	Activity	Description	Revisit Design
Field Observations	1	General Field Notes	Targeted; 2 sites within each park that are relevant to management	Revisit every 3 years starting in 2021
Sensor Data	2	Photopoint data	Targeted; 2 sites within each park that are relevant to management	Revisit every 3 years starting in 2021
Field Sample Collection and Processing	3/4	Water Quality Grab Samples	Targeted; 2 sites within each park that are relevant to management. One sequential replicate will be collected at each site.	Revisit every 3 years starting in 2021
Laboratory Data	5-8	Water Quality parameters	Targeted; 2 sites within each park that are relevant to management	Revisit every 3 years starting in 2021
Quality Control Data	9/10	Field and equipment blanks	One field blank and one equipment blank are collected per park.	Revisit every 3 years starting in 2021

Data Quality Objectives

Data quality values and standards for implementation of the Cave Water Quality Monitoring Protocol are provided in Table B3 through Table B7.

Table B3. Data quality values and definition for Cave Water Quality Monitoring Protocol.

Category	Data Quality Value	Definition	Protocol Considerations
Intrinsic Data Quality	Accuracy	Measurements reflect the true value of the parameter being observed. This applies to measures (length, width, position) or classes (species, types, or categories). Includes components of precision and bias.	Collection of water samples are done in collaboration with USGS water resource professionals. All water samples are processed in laboratories with National Environmental Laboratory Accreditation. Equipment and field blanks are also collected and analyzed. When blanks are found to be contaminated, data from all samples will be flagged.
	Representativeness	Measurements represent conditions at the time of sampling. Combined with accuracy, leads to repeatable data collection.	Parameters and methods are chosen to be representative of the selected fixed sites (i.e., groundwater lakes) at the time of sampling. Area of inference is restricted to those sites.

Table B3 (continued). Data quality values and definition for Cave Water Quality Monitoring Protocol.

Category	Data Quality Value	Definition	Protocol Considerations
Contextual Data Quality	Comparability	The degree to which data can be compared among sample locations, data sources, or periods of time.	Water samples at all sites collected using identical methods consistent with SOP #6 Water Sample Collection. Laboratory methods and use of a certified lab will stay consistent over time and be comparable to other data collected using methods in the USGS National Field Manuel for water quality studies (USGS variously dated). Field and equipment blanks are taken to ensure that samples are not contaminated. Data management and editing is conducted in accordance with SOP #10 of the NGPN Cave Water Quality monitoring protocol.
	Timeliness / Currency	How recent the data need to be to be considered valid for their intended use. Data represents conditions and/or is available and in a format for use at the appropriate time in the decision-making process.	All data are processed within the year they are collected (every 3 years starting in 2021). Data will be certified within one year of collection. Data will be delivered to parks at the appropriate time in the decision-making process to allow managers to apply findings. Annual data reports are produced for JECA and WICA and will provide a summary of the current status of cave water quality parameters. Every 9 years (3 rounds of sampling), larger summary reports will be published and consist of updated analyses of all data, in both graphic and tabular statistical test summary formats.
	Completeness	All data/ measures required to evaluate accuracy representativeness are present; incomplete data sets (either at a location, across sampling locations, or over time) lose utility or relevance. Data records contain values as planned across the period of record.	Methods, sampling plans, and analyses are designed and implemented such that they result in a complete dataset across space and the planned period of record. Since the inference of these data are limited to a fixed site, incomplete data will only affect the analyses at that site and not sampling location. Sequential replicate water samples will be taken at each site to limit the possibility of missing data.

Table B3 (continued). Data quality values and definition for Cave Water Quality Monitoring Protocol.

Category	Data Quality Value	Definition	Protocol Considerations
Representational Data Quality	Consistent Representation	Use of standard definitions when describing data quality or resource quality based on data	Cave water quality data will be compared to water quality standards set by the EPA for drinking water (EPA 2018). All data will be managed in the same format and enter in EQuIS (SOP #10 Data Management). Reporting will be consistent and follow the templates and standards set in the NPS Natural Resource Series.
Data Accessibility	Secure	Access to data, products, and systems limited to appropriate audiences.	Water quality data will be publically available through EQuIS. NGPN staff will continue to work with park resource contacts to ensure protected data (such as cave locations) are identified, labeled, and protected from inadvertent release.

Table B4. Measurement Quality Objectives for Cave Water Quality Monitoring.

Category	Activity	Description
Field Observations	Location Accuracy	Cave locations are mapped and described with enough detail to relocate without the use of GPS equipment. Access points to groundwater lakes are limited and therefore sample location and replicates are within less than 5 m of established sampling location.
Sensor Data / Photopoints	Image resolution	10 megapixel
	Image format	jpeg
Water Sample Collection and Processing, Laboratory Data, and Quality Control Samples	Field and equipment blanks	Sampling is conducted such that equipment and processing has limited effect on water quality and no analytes exceed 2x the method detection limit. See laboratory method performance for specifications by analyte (Table B.5)
	Water Sample MDL, Precision, Bias	See laboratory method performance for specifications by analyte (Table SOP B.5). Laboratory duplicates and blanks are run consistently at the rate per batch determined by the NELAP certified laboratory. The current Quality Assurance Plan for the National Water Laboratory is available at: https://pubs.usgs.gov/of/2005/1263/
	Water Sample Sequential replicates	See laboratory method performance for specifications by analyte (Table SOP B.5). Relative percent difference between sequential replicates less than 20% is considered acceptable (Mueller et al. 2015).

Table B5. Laboratory method performance requirements and analysis methods to be used for water nutrient chemistry analysis.

Analyte	Units	MDL Objective	Transition Value	Precision Objective	Accuracy Objective	Potential Methods conforming to NELAC guidance
Calcium	mg/L	0.022	0.20	± 0.02 or ±10%	± 0.02 or ±10%	Method ID # USGS-NWQL: O-93-125; EPA 200.7
Chloride	mg/L	0.02	0.20	± 0.02 or ±10%	± 0.02 or ±10%	Fishman and Friedman (1989). Method ID # USGS-NWQL: I-2057-85
Fluoride	mg/L	0.01	0.10	± 0.01 or ±10%	± 0.01 or ±10%	Fishman and Friedman (1989). Method ID # USGS-NWQL: I-2057-85
Iron	µg/L	10	100	± 10 or ±10%	± 10 or ±10%	Fishman and Friedman (1989). Method ID # USGS-NWQL: I-1472-87; EPA 200.7
Magnesium	mg/L	0.011	0.10	± 0.01 or ±10%	± 0.01 or ±10%	Fishman and Friedman (1989). Method ID # USGS-NWQL: I-1472-87; EPA 200.7
Manganese	µg/L	0.2	0.20	± 0.02 or ±10%	± 0.02 or ±10%	Fishman and Friedman (1989). Method ID # USGS-NWQL: I-1472-87; EPA 200.7
pH, laboratory	pH	0.1	1.0	± 0.1 or ±10%	± 0.1 or ±10%	Fishman and Friedman (1989).
Potassium	mg/L	0.1	1.0	± 0.1 or ±10%	± 0.1 or ±10%	Standard Method 3120; EPA 200.7
Total dissolved solids	mg/L	20	200	± 20 or ±10%	± 20 or ±10%	Fishman and Friedman (1989). Method ID # USGS-NWQL: I-1750-89
Silica	mg/L	0.018	0.20	± 0.02 or ±10%	± 0.02 or ±10%	Fishman and Friedman (1989). Method ID # USGS-NWQL: I-1472-87; EPA 200.7
Sodium	mg/L	0.1	1.0	± 0.1 or ±10%	± 0.1 or ±10%	Fishman and Friedman (1989). Method ID # USGS-NWQL: I-1472-87; EPA 200.7
Specific conductance	µS/cm	5	50	± 5 or ±10%	± 5 or ±10%	Fishman and Friedman (1989). Method ID # USGS-NWQL: I-2781-85
Sulfate	mg/L	0.02	0.20	± 0.02 or ±10%	± 0.02 or ±10%	Fishman and Friedman (1989). Method ID # USGS-NWQL: I-2057-85
Nitrogen, ammonia	mg/L	0.01	0.10	± 0.01 or ±10%	± 0.01 or ±10%	Method ID # USGS NWQL: I-2522-90; EPA 350.1
nitrogen, nitrite	mg/L	0.001	0.01	± 0.001 or ±10%	± 0.001 or ±10%	Fishman (1993). Method ID # USGS NWQL: I-2540-90

Table B5 (continued). Laboratory method performance requirements and analysis methods to be used for water nutrient chemistry analysis.

Analyte	Units	MDL Objective	Transition Value	Precision Objective	Accuracy Objective	Potential Methods conforming to NELAC guidance
nitrogen, nitrite + nitrate	mg/L	0.01	0.10	± 0.01 or ±10%	± 0.01 or ±10%	Patton and Kryskall (2011) Method ID # USGS-NWQL:I-2548-11
Total nitrogen, filtered	mg/L	0.05	0.5	± 0.05 or ±10%	± 0.05 or ±10%	Patton and Kryskall (2003) Method ID # USGS I-4650-03
Total nitrogen, unfiltered	mg/L	0.05	0.5	± 0.05 or ±10%	± 0.05 or ±10%	Patton and Kryskall (2003) Method ID # USGS I-4650-03
Phosphorus	mg/L	0.003	0.03	± 0.003 or ±10%	± 0.003 or ±10%	EPA 365.1
Orthophosphorous	mg/L	0.004	0.04	± 0.004 or ±10%	± 0.004 or ±10%	Method ID # USGS I-2781-85; EPA 365.2
Arsenic	µg/L	0.05	0.5	± 0.05 or ±10%	± 0.05 or ±10%	Garabino et al. (2006). Method ID # USGS-NWQL: I-2020-05; EPA 200.8
Chromium	µg/L	0.5	5.0	± 0.5 or ±10%	± 0.5 or ±10%	Garabino et al. (2006). Method ID # USGS-NWQL: I-2020-05; EPA 200.8
Copper	µg/L	0.2	0.20	± 0.02 or ±10%	± 0.02 or ±10%	Garabino et al. (2006). Method ID # USGS-NWQL: I-2020-05; EPA 200.8
Lithium	µg/L	0.15	0.15	± 0.015 or ±10%	± 0.015 or ±10%	Garabino et al. (2006). Method ID # USGS-NWQL: I-2020-05; EPA 200.8
Manganese	µg/L	0.4	4.0	± 0.4 or ±10%	± 0.4 or ±10%	Garabino et al. (2006). Method ID # USGS-NWQL: I-2020-05; EPA 200.8
Strontium	µg/L	0.5	5.0	± 0.5 or ±10%	± 0.5 or ±10%	Garabino et al. (2006). Method ID # USGS-NWQL: I-2020-05; EPA 200.8
Uranium, natural	µg/L	0.01	0.10	± 0.01 or ±10%	± 0.01 or ±10%	Garabino et al. (2006). Method ID # USGS-NWQL: I-2020-05; EPA 200.8
Vanadium	µg/L	0.1	1.0	± 0.1 or ±10%	± 0.1 or ±10%	Garabino et al. (2006). Method ID # USGS-NWQL: I-2020-05; EPA 200.8
Zinc	µg/L	2	20	± 2 or ±10%	± 2 or ±10%	Garabino et al. (2006). Method ID # USGS-NWQL: I-2020-05; EPA 200.8
Benzene	µg/L	0.026	0.26	± 0.026 or ±10%	± 0.026 or ±10%	Method ID # USGS-NWQL:0-4436-16; EPA 424.3

Table B5 (continued). Laboratory method performance requirements and analysis methods to be used for water nutrient chemistry analysis.

Analyte	Units	MDL Objective	Transition Value	Precision Objective	Accuracy Objective	Potential Methods conforming to NELAC guidance
Ethylbenzene	µg/L	0.036	0.36	± 0.036 or ±10%	± 0.036 or ±10%	Method ID # USGS-NWQL:0-4436-16; EPA 424.3
m- and p-Xylene	µg/L	0.08	0.8	± 0.08 or ±10%	± 0.08 or ±10%	Method ID # USGS-NWQL:0-4436-16; EPA 424.3
Methyl tert-butyl ether	µg/L	0.1	1.0	± 0.1 or ±10%	± 0.1 or ±10%	Method ID # USGS-NWQL:0-4436-16; EPA 424.3
o-Xylene	µg/L	0.032	0.32	± 0.032 or ±10%	± 0.032 or ±10%	Method ID # USGS-NWQL:0-4436-16; EPA 424.3
Toluene	µg/L	0.05	0.5	± 0.05 or ±10%	± 0.05 or ±10%	Method ID # USGS-NWQL:0-4436-16; EPA 424.3

Table B6. Laboratory accreditation requirements for Cave Water Quality Monitoring Protocol.

Activity	Parameter	Accreditation Requirement	Location of Certification Documentation[1]
Water Chemistry	Water chemistry-nutrients	Laboratory meets all USGS Brach of Quality Systems standards and NELAP	Copy of certification from USGS-NWQL on file in Network office
Water Chemistry	Water chemistry-physical characteristics	Laboratory meets all USGS Brach of Quality Systems standards and NELAP	Copy of certification from USGS-NWQL on file in Network office
Water Chemistry	Water chemistry-metals	Laboratory meets all USGS Brach of Quality Systems standards and NELAP	Copy of certification from USGS-NWQL on file in Network office
Water Chemistry	Water chemistry-hydrocarbons	Laboratory meets all USGS Brach of Quality Systems standards and NELAP	Copy of certification from USGS-NWQL on file in Network office

Table B7. Data Protection standards for Cave Water Quality Monitoring. With the exceptions noted, all data collected are to be made publicly available in a timely fashion.

Category	Type of Data	Level of Protection	Rules for Dissemination
Location & Resource Data and Information	Water Quality Data	Unprotected	Data available online as public information.
	Permanent Sampling Locations and Entrances to Cave Systems	Legally protected	Redacted where appropriate
Personally Identifiable Information	Non-NPS Staff Information	Legally Protected	All but first name and last initial redacted from public release

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