



Water Quality Monitoring Protocol for Streams and Springs in the Southern Colorado Plateau Network

Natural Resource Report NPS/SCPN/NRR—2016/1298



ON THE COVER

Mancos River, Mesa Verde National Park, 2007. NPS photo.

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Southern Colorado Plateau Network Park Units

Park	Abbreviation	State	Area (hectares ^a)
Aztec Ruins National Monument	AZRU	NM	108
Bandelier National Monument	BAND	NM	13,619
Canyon De Chelly National Monument	CACH	AZ	33,929
Chaco Culture National Historical Park	CHCU	NM	13,290
El Malpais National Monument	ELMA	NM	44,494
El Morro National Monument	ELMO	NM	421
Glen Canyon National Recreation Area	GLCA	AZ/UT	501,253
Grand Canyon National Park	GRCA	AZ	477,792
Hubbell Trading Post National Historic Site	HUTR	AZ	65
Mesa Verde National Park	MEVE	CO	21,146
Navajo National Monument	NAVA	AZ	146
Petrified Forest National Park	PEFO	AZ	56,340 ^b
Petroglyph National Monument	PETR	NM	1,188
Rainbow Bridge National Monument	RABR	UT	65
Salinas Pueblo Missions National Monument	SAPU	NM	397
Sunset Crater Volcano National Monument	SUCR	AZ	1,230
Walnut Canyon National Monument	WACA	AZ	1,316
Wupatki National Monument	WUPA	AZ	14,327
Yucca House National Monument	YUHO	CO	14

a Hectares are derived from the "NPS Fee Acres" column of the NPS Land Resources Division, Listing of Acreage (Summary), available from <http://landsnet.nps.gov/Acreage.asp> (accessed February 24, 2016).

b Recent boundary addition to Petrified Forest NP brings the total area to 89,604 ha.

Acronyms and Abbreviations

Acronym, abbreviation or symbol	Definition
303(d)	Section 303(d) of Clean Water Act requiring a reporting of waters not meeting standards
as N	as Nitrogen
as P	as Phosphorus
ADEQ	Arizona Department of Environmental Quality
AZ	Arizona
CDPHE	Colorado Department of Public Health and Environment
cfs	cubic feet per second
CO	Colorado
CWA	Clean Water Act
DEQ	Department of Environmental Quality
DIW	De-ionized water
DO	Dissolved oxygen
I&M	Inventory and monitoring
µg/L	micrograms per liter
µS/cm	microsiemens per centimeter [specific conductance]
mg/L	milligrams per liter
NNEPA	Navajo Nation Environmental Protection Agency
NAU	Northern Arizona University
NM	New Mexico
NMED	New Mexico Environment Department
NPS	National Park Service
NPS-WRD	National Park Service Water Resources Division
NTU	Nephelometric turbidity units [turbidity]
Q	Discharge (in cubic feet per second)
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
SCPN	Southern Colorado Plateau Network
SpC	Specific conductance
SOP	Standard operating procedure
STORET	USEPA Storage and Retrieval System database
TDS	Total dissolved solids
TMDL	Total maximum daily loading
UDEQ	Utah Division of Environmental Quality
USEPA	U.S. Environmental Protection Agency
USGS	United States Geological Survey
UT	Utah

Executive Summary

Water quality is an indicator of aquatic and riparian ecosystem health and is influenced by the interaction of geology, hydrology, and watershed characteristics on the Colorado Plateau. It is sensitive to natural disturbances and anthropogenic stressors across a range of spatial scales. The Southern Colorado Plateau Network (SCPN) of the National Park Service (NPS) identified water quality as a core vital sign and chose to conduct long-term monitoring of the water quality of streams and springs in network parks. This protocol narrative and 18 associated Standard Operating Procedures (SOPs) explain the rationale, describe the process, and provide the field methods used to monitor water quality in SCPN parks. Seven appendices provide supplemental information: a yearly task list; a list of water quality monitoring sites and plans for SCPN parks; equipment decontamination procedures, lab standards and guidelines; documentation of the databases used to manage water quality data; a sample water quality data summary report; and a complete list of equipment used in the SCPN water quality monitoring process. Appendix H provides links to the SOPs, which are published separately from this narrative.

To identify streams and springs where potential water quality monitoring sites might be located, SCPN reviewed (1) water quality data inventory and analysis reports prepared by the Water Resources Division (WRD) of the NPS, (2) a United States Geological Survey (USGS) summary and review of available water quality data from streams in SCPN parks (Brown 2008), (3) data collected during a Level 1 water quality inventory of streams in SCPN parks (Macy and Monroe 2006), and (4) results of water quality planning meetings with natural resource staff of network parks. SCPN selected streams and springs at the following parks: Bandelier National Monument, Canyon de Chelly National Monument, El Morro National Monument, Glen Canyon National Recreation Area, Grand Canyon National Park, Mesa Verde National Park, Navajo National Monument, Salinas Pueblo Missions National Monument, Walnut Canyon National Monument, Wupatki National Monument, and Yucca House National Monument. SCPN will establish monitoring sites, either in association with other network monitoring activities where substantial historical water quality data are available, or at locations selected as high priority through consultation with park managers.

SCPN stream water quality monitoring sites will be visited three to four times each year, and water quality data will be collected at spring monitoring sites once every five to seven years. At each stream monitoring site, SCPN will collect water quality core parameter data as required by the NPS Water Resources Division, which include temperature, pH, specific conductance, dissolved oxygen, turbidity and discharge. In addition, the network will collect data on *E. coli* and coliform bacteria, as well as a suite of analytes that may include nutrients, major elements and ions, and dissolved trace elements. Only NPS core water quality data will be collected at springs monitoring sites. The methods described in this protocol are modified from protocols developed by the USGS, and the NPS Northern Colorado Plateau Network.

The purpose of water quality monitoring of streams and springs in SCPN parks is to track the changes in water quality in support of the NPS's long-term goals to protect pristine water quality and improve impaired water quality. Specific objectives of stream and spring water quality monitoring are to

- determine status and trends in selected core water quality parameters (water temperature, pH, specific conductance, dissolved oxygen, discharge and turbidity) at selected springs and sites in priority streams within SCPN parks
- determine status and trends of selected water quality constituents, including bacteria,

nutrients, major elements, and trace metals at selected sites in priority streams within SCPN parks

- compare water quality data against state standards for chronic exceedances. Multiple exceedances in a year typically indicate non-compliance

Monitoring conducted in accordance with this protocol will contribute to our understanding of the ecological integrity of network park units by providing information about the health of their stream and spring ecosystems.

Acknowledgments

The authors would like to thank Allison Snyder for her valuable assistance in developing and fine tuning this protocol. We are also grateful to have been able to draw on the work of other NPS units, including the Water Resources Division and the Northern Colorado Plateau Network, as well as the USGS National Water Quality Laboratory.

1 Introduction

1.1 Background

The Southern Colorado Plateau Network (SCPN) is comprised of nineteen national park units. These parks are distributed across the states of Arizona, Colorado, New Mexico, and Utah (Figure 1). Nine of the parks are located on, or are adjacent to, Navajo Nation lands. Most of the parks are in the Colorado River Basin. Some of the parks in New Mexico are on the eastern side of the Continental Divide and are in the Rio Grande Basin. The parks vary widely in size, from Yucca House National Monument (YUHO), the smallest, at approximately 10 acres, to Grand Canyon National Park (GRCA) and Glen Canyon National Recreation Area (GLCA) which are both larger than 1.2 million acres.

Knowing the condition of natural resources in parks is fundamental to the National Park Service's (NPS) ability to manage park resources. As part of the NPS Inventory and Monitoring Program, SCPN conducts ecological monitoring to collect, organize, analyze and synthesize natural resource data and information about its parks. The intent of ecological monitoring is to track, through time, changes in the condition of particular resources, or in the status of indicators of ecological integrity. "Vital signs" are selected physical, chemical, and biological elements or processes of park ecosystems that represent the overall health or condition of the park, known or hypothesized effects of stressors, or elements that have important human values.

SCPN has identified a suite of vital signs which include signs for aquatic and riparian ecosystems and describe the ecological health of network parks (Thomas et al. 2006). Water quality is monitored in network parks as an indicator of ecosystem integrity, as a component of watershed condition, and to document water quality conditions in relation to state and federal regulations.

1.2 Hydrologic setting and influences on water quality

On the Colorado Plateau, both the semi-arid climate and geology strongly influence water resources and water quality. Perennial streams are relatively rare and surface water is scarce in many SCPN parks. In some parks surface water only occurs at springs (NAVA, SAPU, and YUHO). Springs are significant hydrologic and biotic resources in the desert southwest, and a wide variety of spring types occur in SCPN parks. Hanging gardens are a spring type characteristic of the Colorado Plateau. These vertical oases occur where groundwater seeps or trickles from a saturated vertical sandstone face, creating a large area of wetted rock, which supports habitat for wetland plants, including endemic species. Hanging gardens occur in CACH, GLCA, GRCA, MEVE, NAVA, and WACA. Tinajas, small water catchments eroded into bedrock that hold water for a few weeks or months, also exist in some SCPN parks, as well as small man-made reservoirs developed for livestock, wildlife, or NPS water supply.

Intermittent or ephemeral washes are characteristic of most SCPN parks (CACH, CHCU, ELMA, HUTR, NAVA, PEFO, PETR, WACA, and WUPA), and many of these have been altered to enhance stream-bank stability, channel flow, and water storage, or to provide drainage for storm water. Stream channels in many of the parks incised rapidly during the 1900s. This was probably the result of stabilization efforts, flow diversion and the invasion of non-native species.

Segments of the Colorado River and its major tributaries are within GLCA and GRCA. Other major rivers that flow through or border SCPN parks include the Animas River (AZRU), the Rio Grande (BAND), the Mancos River (MEVE), the Puerco River (PEFO), and the Little Colorado River (WUPA). Flow in all of these rivers is partially or entirely controlled by dams or diversion structures.

Flowing water in SCPN parks can generally be characterized as moderate to high in dis-

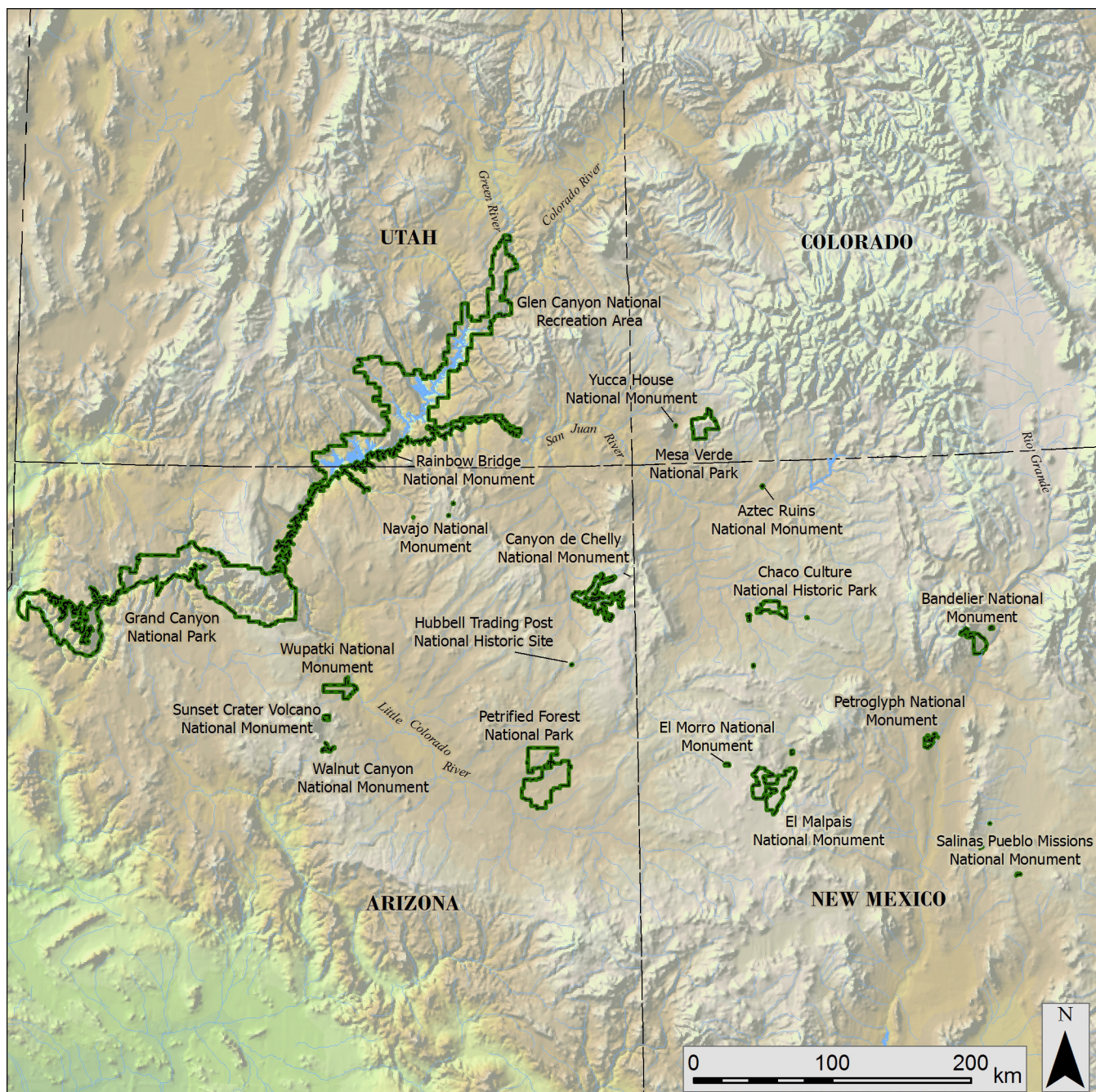


Figure 1. Southern Colorado Plateau Network parks are distributed across four western states: Arizona, Colorado, New Mexico, and Utah.

solved solids, turbid at higher flows, slightly basic in pH, well-buffered, and dominated by calcium, magnesium, and sodium cations; and carbonate, sulfate and chloride anions. Notable exceptions are the higher elevation streams in BAND which drain volcanic terrain. The seasonality of precipitation, snowmelt runoff, and monsoonal floods, combined with a landscape where water

infiltration and groundwater storage are generally low, create a high degree of spatial and temporal variation in discharge, temperature, and dissolved solids within network waters. Rivers tend to be very turbid during runoff events because much of the landscape lacks dense vegetative cover and is highly vulnerable to erosional forces. The majority of sediment washed from the landscape is

transported during floods, but in some cases, the fine sediment that contributes to turbidity can cloud the water for months after a flood event. Endemic aquatic organisms are adapted to the natural high sediment loading and turbidity of SCPN rivers.

Climate exerts a strong influence on hydrologic patterns and is a prime factor controlling ecosystem distribution (Bailey 1995, 1998). The southern Colorado Plateau has a semi-arid climate characterized by periods of drought and irregular precipitation, relatively warm to hot growing seasons, and long winters with sustained periods of freezing temperatures (Hunt 1967). Much of the moisture from precipitation—approximately 10–25 cm per year in many SCPN locations (Montgomery and Harshbarger 1992)—is lost through evaporation due to nearly vertical noontime solar position, clear skies, and dry, thin, high-elevation air (Durrenberger 1972), or to groundwater infiltration, which recharges local and regional aquifers.

A broad boundary that coincides with the mean northwestern extent of summer monsoonal precipitation patterns divides the Colorado Plateau into two climatic regions (Petersen 1994; Figure 2). In the southern portion of the plateau, peak precipitation events occur in winter as snowfall and in summer as moisture from southern monsoonal weather patterns (Bureau of Land Management 2014). Summer monsoonal precipitation events commonly cause large runoff events in streams of the southern Colorado Plateau. The amount of summer precipitation generally weakens from southeast to northwest. North of the boundary, winter precipitation dominates the northwestern portion of the Colorado Plateau. All SCPN park units lie southeast of this climatic boundary.

This climatic pattern contributes to high inter-seasonal and inter-annual variability in precipitation in the SCPN region (Ehleringer et al. 1999). From November to March, the

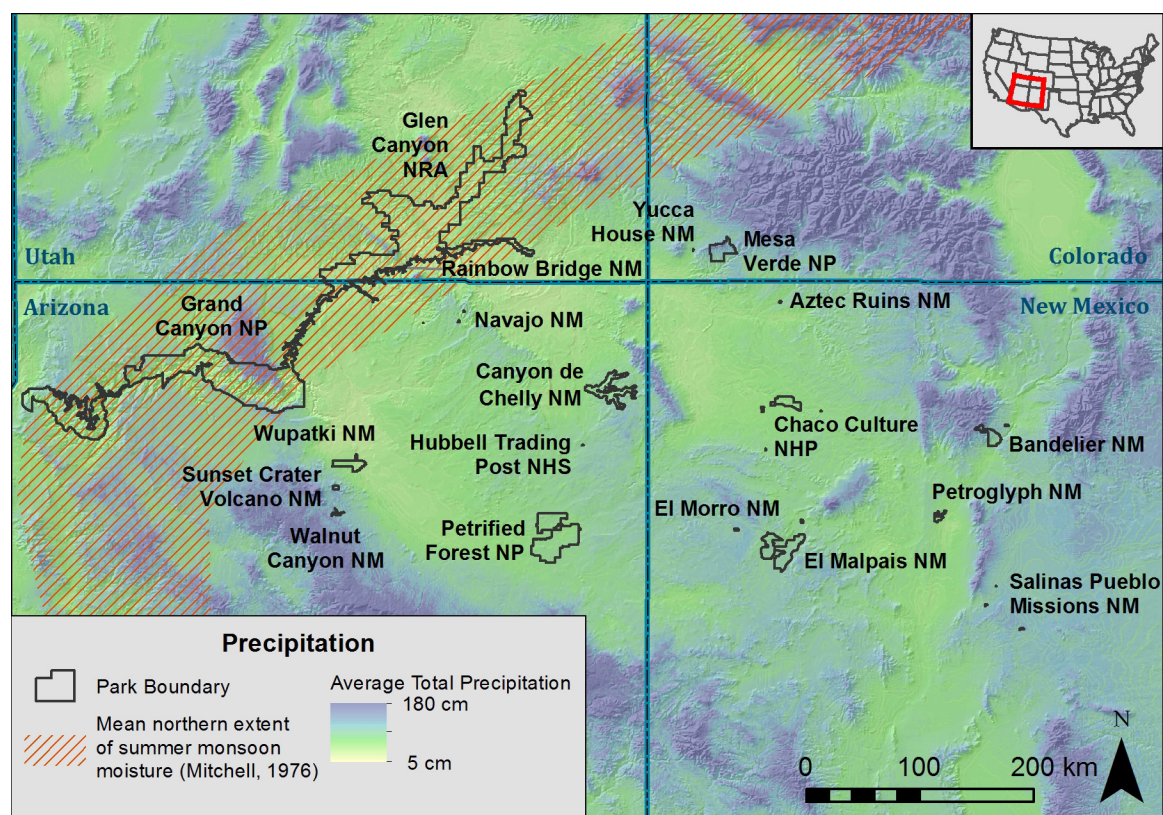


Figure 2. Map of average annual precipitation on the Colorado Plateau. The mean northern extent of summer monsoon moisture marks the boundary of two climatic regions (Mitchell 1976).

dominant weather patterns on the southern Colorado Plateau include precipitation from Pacific region storms. December and January tend to experience spatially-heterogeneous precipitation that is strongly influenced by elevation, while trends in February and March show an overall increase in precipitation. By May, drier conditions again prevail on the plateau and last until late June when monsoonal circulation begins to gain strength (Mock 1996).

1.3 Water use in SCPN parks

Water is an important resource for natural systems in SCPN parks. It has a strong influence on the abundance, distribution and diversity of floral and faunal assemblages, and is the major force responsible for the sculpting of the dramatic southwestern landscapes that define many SCPN parks. In addition, water flowing on the surface or underground is a major mechanism for nutrient and ion transport in natural systems. Equally as important as water's role in natural systems of network parks are human uses of water.

Human use of water includes domestic, recreational, livestock, and agriculture use, and often predates parks. In SCPN parks, water is used as a domestic supply for park employee residences, park operations, and visitor facilities, including concessionaire-run lodges and campgrounds. Larger rivers and the one large reservoir in the network (GLCA) attract a lot of visitors for water-based recreation, including boating, swimming and fishing.

In addition to wildlife, domestic livestock use water at its source, or from spring developments or diversions. Water is diverted from rivers or streams flowing into or along the boundaries of many SCPN parks for stock watering and irrigation, and for domestic, recreational, municipal, and industrial uses (MEVE, CACH, HUTR, GLCA, GRCA, WACA, and WUPA). These diversions generally pre-date the establishment of the parks.

Water quality can have a substantial influence on human uses of the water. At the

same time, human uses of water may have substantial effects on water quality. The long term strategic goal of the NPS is to significantly improve the water quality in our national parks. Water dependent ecosystems in SCPN's unique landscapes, as well as all other natural and cultural resources found therein, are protected by the NPS Organic Act and the enabling acts or proclamations for each park.

1.4 Clean Water Act Section 303(d) and impaired waters in SCPN parks

Under the Clean Water Act of 1972 (CWA), states must identify all waters that do not meet, or are not expected to meet water quality standards (U.S. Environmental Protection Agency [USEPA] 2013). States assess waters to identify water quality-limited waters, and the public is notified through what are known as "303(d) Lists", which refers to the section of the CWA in which the requirement is described (CWA 1972). Each state updates their 303(d) list every two years using data collected by state agencies or other entities. States must determine if and why waters do not meet water quality standards, and develop plans for bringing problem water bodies into compliance. These plans are based on the Total Maximum Daily Loading of contaminants to the water and are referred to as "TMDL" plans. TMDL is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards, as well as an allocation of that load among the various sources of that pollutant (USEPA n.d.). States can consider a wide variety of remedies, including reducing the contaminant loading, changing the designated protected uses (such as from Cold Water Fishery to Warm Water Fishery) to more accurately reflect ambient conditions, or documenting that the "poor" quality of the water is due to natural causes and is not correctable. In SCPN parks, six stream reaches were included in the most recent state 303(d) lists (Table 1) (ADEQ 2012, NMED 2012).

The NPS does not have legal authority to enforce water quality standards. Actual legal

Table 1. Reaches of streams in NPS parks that are currently identified as water quality impaired on Arizona and New Mexico 303(d) lists (ADEQ 2012, NMED 2012).

Park	Waterbody	Reach	Cause of impairment	Other
AZRU	Animas River	Southern Ute Tribe boundary to Estes Arroyo	<i>E. coli</i> , total phosphorus	TMDLs completed in 2013
BAND	Rito de los Frijoles	From Upper Crossing to the Rio Grande	Aluminum, DDT in fish tissue	Assessment status in 2012
BAND	Rio Grande	From San Ildelfonso Pueblo boundary to Cochiti Reservoir	<i>E. coli</i> , adjusted gross alpha, PCBs, PCBs in fish tissue, turbidity	Assessment status in 2012
GRCA	Colorado River	From Parashant Canyon to Diamond Creek	Selenium (total) and suspended sediment	Selenium TMDL initiated in 2011. Suspended sediment TMDL to be initiated in 2014.
GLCA	Colorado River	From Lake Powell to the Paria River	Selenium (total)	Assessment status in 2008
GLCA	Paria River	From Utah border to Colorado River	Suspended sediment and <i>E. coli</i>	Assessment status in 2008

enforcement of the recreational bacterial standard is the responsibility of the appropriate tribal or state authority, or with EPA if a state fails to take action. However, the NPS has the authority to issue advisories and restrict access, if necessary, to safeguard park visitors.

1.5 State standards and protected uses

The four states of Arizona, Colorado, New Mexico, Utah, and the Navajo Nation have developed regulatory systems following Clean Water Act and EPA guidance that identify specific standard concentrations or measures for water quality constituents that are required to protect a class of uses. The specific protected uses of water vary somewhat state by state, but generally include irrigated agriculture, domestic water supply, cold-water aquatic life, warm-water aquatic life, water-based recreation and livestock watering. Quantitative standards are established for parameters the states and EPA believe are necessary to protect each of these uses. Standards are typically of two types—most are fixed quantities, others vary in response to another water quality value, typically hardness or temperature. In some cases qualitative standards or recommended levels are used.

Thresholds of concern for SCPN waters will be the same as the water quality standards used by states to evaluate compliance with CWA. Sources for the current water quality standards for each of the four states where SCPN parks are located, and for the Navajo Nation are listed in Table 2. The USEPA's guidelines to help states comply with federal regulations addressing water quality standards are also listed. These standards will help to alert managers of potential problems because they are quantitative and have built-in margins of safety.

States have narrative standards to protect water bodies against pollutants for which quantitative standards do not exist, as well as quantitative numeric standards for acute and chronic exceedances. In practice, consultation with state water quality professionals is necessary to determine if acute and chronic exceedances warrant action on the part of park managers. In some cases, acute exceedances may result from natural causes that cannot reasonably be controlled by management.

Table 2. Sources of water quality standards documentation for the southern Colorado Plateau regions, which include states, the Navajo Nation, and the U.S. Environmental Protection Agency (USEPA).

State/Agency	Regulation	Website
Arizona	Arizona Administrative Code, Title 18. Environmental Quality, Chapter 11 (State of Arizona 2009)	http://www.azsos.gov/public_services/Title_18/18-11.htm
Colorado	Water Quality Control Commission Regulations: 5 CCR 1002, Regulations 21 through 94 (CDPHE 2015)	https://www.colorado.gov/pacific/cdphe/water-quality-regulations
New Mexico	New Mexico Surface Water Quality Standards, Water Quality Rules and Regulations (New Mexico Environment Department 2013)	http://www.nmenv.state.nm.us/swqb/Standards/
Utah	Standards of Quality for Waters of the State, R317-2, Utah Administrative Code. Utah Dept of Environmental Quality, Div. of Water Quality (Utah Department of Administrative Services 2015)	http://www.rules.utah.gov/publicat/code/r317/r317-002.htm
Navajo Nation	Navajo Nation Water Quality Standards (Navajo Nation Environmental Protection Agency 2004)	http://www.navajonationepa.org/lawreg.html
USEPA	Access to water quality standards resources, including basic information, laws and regulations, policy and guidance, and all current state, tribal and territorial water quality standards (USEPA 2015)	http://www.epa.gov/waterscience/standards/

2 Developing a Water Quality Protocol for the Southern Colorado Plateau Network

The purpose of a vital signs monitoring program is to provide data that will detect long-term environmental change, provide insights into the ecological consequences of these changes, and help park managers to determine if research or management actions are needed to address or understand the changes (Noon et al. 1999).

One of the NPS' long-term strategic goals has been to significantly improve the water quality in park water bodies. Due to the high ecological, management, and legal significance of waters in the southwestern U.S., SCPN and the staff of network parks identified water quality of streams and springs as a core vital sign to be monitored (Thomas et al. 2006).

2.1 Purpose and objectives of water quality monitoring

The purpose of SCPN's water quality monitoring program is to track the changes in water quality of streams and springs in network parks to support the NPS's long-term goals to protect pristine water quality and improve impaired water quality.

SCPN's specific measurable objectives are related to water quality standards determined by the states and the Navajo Nation where SCPN parks are located (Table 2). These standards provide the framework for developing specific monitoring questions, a sampling plan, and data analysis techniques that will answer the monitoring questions. The amount of data collected, variability of the results due to natural conditions, and variability due to analysis techniques will introduce a level of uncertainty that must be quantified in the interpretation of results.

Specific objectives of stream and spring water quality monitoring for the SCPN parks are as follows:

1. Determine status and trends in selected core water quality parameters (water temperature, pH, specific conductance, dissolved oxygen, turbidity and discharge) at selected sites in priority streams within SCPN parks.
2. Determine status and trends of selected water quality constituents that include bacteria, nutrients, major elements, and trace metals, at selected sites in priority streams within SCPN parks.
3. Compare water quality data against state standards to detect chronic exceedances. Multiple exceedances in a year typically indicate non-compliance.

For SCPN water quality monitoring, sampling frequency will occur at a screening level of three to four times per year. Occasionally, the network will conduct more intensive monitoring in response to source and flow conditions where visitors use the water as a source of drinking water or for full- or partial-body contact recreation. This screening sample frequency provides a general indicator of the relative magnitude of contamination, but is not adequate for enforcement-level monitoring because most states require multiple samples per month to determine compliance with water quality standards. For this reason, the results will be used to inform the NPS and visitors about general conditions, but not to take actions, such as a closure, in response to the results of individual samples.

2.2 Water quality core parameters

The NPS core water quality parameters for streams and springs include temperature, pH, specific conductance (at 25°C), dissolved oxygen, turbidity and discharge. These core parameters were established by a national review panel convened by the National Park Service-Water Resources Division (NPS-WRD). This group recommended the core parameter suite should be measured in water bodies across all NPS monitoring networks (Freshwater Workgroup Subcommittee 2002). Occurrences of core water

quality parameter exceedances at streams in SCPN parks are summarized in Section 3.4.

2.3 Water constituents

Water quality monitoring is defined by the USEPA as the sampling and analysis of water constituents and conditions. Water constituents can be those naturally occurring in water, or they can be introduced pollutants, such as pesticides, metals and oil. In addition to water quality core parameters, SCPN will collect data on *E. coli* and coliform bacteria, as well as a suite of analytes that may include nutrients, major elements and ions, and dissolved trace elements.

2.3.1 Total coliforms and *E. coli*

The purpose of monitoring fecal bacteria is to provide an indication of the risk of contracting enteric (intestinal) diseases for recreational users who come into contact with, and/or accidentally ingest park waters through immersion or full-body contact recreation-like swimming. The most commonly tested indicator bacteria in water are total coliforms, fecal coliforms, *E. coli*, fecal streptococci, and enterococci. Total coliforms are a group of bacteria that are widespread in nature and, while they occur in human feces, they also occur naturally in places outside the human body. Therefore, total coliforms are no longer recommended as an indicator of contamination in recreational waters (USEPA 2012). Fecal coliforms are a subset of total coliforms that are a more specific indication of fecal contamination; however this group also contains species which are not necessarily fecal in origin. The USEPA recommends testing for *E. coli* and enterococci indicators in place of total and fecal coliform indicators because epidemiological studies indicate that *E. coli* and enterococci show a direct correlation with swimming-associated gastrointestinal illness rates, while fecal coliforms do not (USEPA 1986). Because enterococci survive in salt water, all water quality standards applicable to SCPN parks use *E. coli*.

While most parks have had only sparse bacteriologic sampling, elevated *E. coli* levels

are a potential water quality concern at many SCPN parks. Activities contributing to elevated *E. coli* and total coliform counts can occur upstream of, or within the park, and may include visitor activities in and around water sources, grazing and other agricultural activities, wildlife use, and upstream residential development. Most parks had little to no bacteriologic data.

2.3.2 Nutrients

Nutrient levels are a water quality concern because they control primary productivity and are a major factor in the biotic composition in streams. Nutrients come from both anthropogenic and natural sources, including the weathering of bedrock, decomposition of organic matter, land use activities within the watershed, atmospheric deposition, runoff, discharge from wastewater facilities, and others. Nutrients monitored by SCPN include dissolved ammonia, nitrate, nitrite, and orthophosphate. State water quality standards vary in their treatment of nutrients; most include ammonia due to its toxicity to fish but, with the exception of Utah, generally do not include nitrate, nitrite, and orthophosphate in their aquatic life criteria. However nitrate and nitrite criteria do exist for drinking water supplies.

2.3.3 Major elements

General water quality characteristics are quantified by collecting samples for major elements, including calcium, chloride, fluoride, magnesium, potassium, silica, and acid neutralizing capacity. Total dissolved solids (TDS) consist mainly of the ions listed above plus carbonate/bicarbonate.

Elevated TDS levels are a water quality concern throughout the network. Activities contributing to elevated TDS concentrations occur upstream and within the park and include: natural geologic sources, agriculture, wastewater treatment, upstream residential development, or visitor activities in and around water sources.

2.3.4 Trace metals

Trace metals were identified as a potential

water quality concern in several SCPN parks. Activities or sources that could contribute to elevated metals and/or water quality exceedances include historic and current mining, and gas development activities adjacent and upstream of a park, nearby coal-fired power plants and waste incinerators, the underlying geology, and upstream wastewater discharges. Limited trace element data were collected as part of an SCPN Level 1 baseline water quality assessment (Macy and Monroe 2006). Selenium is a trace element of particular concern throughout much of the Colorado River basin, with elevated levels occurring in some places due to irrigation practices and development (Butler and Lieb 2002). Natural background levels are high and associated with particular soil types and geological features, such as Mancos Shale. Exceedances are summarized in Section 3.4.

3 Summary of Historical Water Quality Data for the Southern Colorado Plateau Network

3.1 Summary of existing data

Limited water quality data have been available for most SCPN parks, however, many parks lack enough data to adequately characterize the water quality of their water sources. The NPS-WRD assembled existing water quality data from six USEPA databases during the 1990's. These reports, known as the 'Horizon Reports' (National Park Service Water Resources Division 1996, 1997a & b, 1999a & b, 2000) provided a review of historical regulatory water quality monitoring data for each park. However, these databases are not complete as the results of many studies were not included. Additional sources of water quality data include reports and published manuscripts produced by individual researchers, a report by the USGS that compiled, reviewed and summarized water quality data from 1925 to 2004 for the 19 SCPN parks (Brown 2008), and a Level 1 water quality baseline assessment conducted by the USGS during 2004-2005 (Macy and Monroe, 2006). The USGS/WRD-Colorado also developed a water quality database for SCPN parks. This database enabled us to assess the temporal and spatial distribution of available water quality data. It provides a useful tool for evaluating historical water quality for waters within and around SCPN park units.

Data summaries from these sources help to identify historical and current water quality conditions in SCPN parks. Table 3 summarizes information about the sources of all available water quality data for SCPN parks from 1925 through 2005. Additional data collected since 2005 can be found in recent SCPN annual water quality data summary reports for BAND, CACH, GLCA, GRCA, and MEVE, which can be accessed from the SCPN website (<http://science.nature.nps.gov/im/units/scpn/>).

3.2 Availability of streamflow data

Flow is the key parameter for physical conditions in rivers; it is needed to interpret concentration data and calculate water quality loadings. Although part of the core water quality suite (as discharge), it is singled out here because measuring flow is operationally different from other water quality monitoring. The USGS, Navajo Nation, and Los Alamos National Laboratory maintain streamflow gaging stations in or near several SCPN parks (see Table 17-1 in SOP #17). The historical and ongoing data provided by these gaging stations are critical for the analysis of water quality trends and loading, and land use and climate changes.

3.3 Historic variability of water quality data

Water quality data for SCPN parks is extremely limited (Brown 2008) and much of the available data was collected twenty or more years ago. Most constituents have not been sampled regularly enough to determine if exceedances of state standards or federal criteria is a chronic occurrence in these surface waters. USGS (Brown 2008) evaluated available water quality data for SCPN parks and classified parks as 'data rich' or 'data deficient' based on the number and type of samples, and length of period of record. Data deficient parks included parks without any water quality data, and parks with fewer than ten samples for any given site type; data rich parks included parks with a lengthy monitoring record and/or greater than 100 water quality samples. Most of the available data falls into one of five constituent classes: field measurements, major ions, nutrients, trace elements and microorganisms. It is also evident that most data for the parks are for surface-water sites and springs, with the exception of Glen Canyon National Recreation Area, which has a large amount of lake data. Using this approach, only four parks have a data-rich history (i.e., greater than 100 samples for a given constituent class and site type) for one or more sites and one or more constituent classes; these parks include BAND, CHCU, GLCA, and GRCA.

Table 3. Compilation of historical water quality data for SCPN parks from 1925 to 2005 (Brown 2008). Number of sites, samples and results with sample period for all monitoring sites located in SCPN parks by parameter category. Selected parameter categories shown include constituents of common concern for SCPN; all categories represent samples from the water column. Core field parameters include pH, specific conductance, dissolved oxygen, and water temperature.

Park	Parameter category	Number of sites	Number of samples	Number of results	Earliest sample	Latest sample
Aztec Ruins NM	Major ions	2	6	42	4/5/2005	11/3/2005
	Trace elements	2	6	150	4/5/2005	11/3/2005
	Core field parameters	2	6	32	4/5/2005	11/3/2005
	Nutrients	2	6	24	4/5/2005	11/3/2005
	Microorganisms	0	0	0	-	-
Chaco Culture NHP	Major ions	11	112	1299	8/6/1976	12/6/2005
	Trace elements	7	154	1180	8/1/1976	12/6/2005
	Core field parameters	12	660	917	8/1/1976	12/6/2005
	Nutrients	7	54	443	8/6/1976	12/6/2005
	Microorganisms	2	2	2	2/17/1977	6/9/1982
El Malpais NM	Major ions	2	4	4	9/25/1993	10/2/1993
	Trace elements	0	0	0	-	-
	Core field parameters	10	16	28	10/4/1989	10/4/1995
	Nutrients	0	0	0	-	-
	Microorganisms	0	0	0	-	-
El Morro NM	Major ions	8	22	139	2/28/1968	12/22/2005
	Trace elements	4	11	19	2/28/1968	12/22/2005
	Core field parameters	8	17	50	2/28/1968	12/22/2005
	Nutrients	8	21	28	2/28/1968	12/22/2005
	Microorganisms	0	0	0	-	-
Glen Canyon NRA	Major ions	75	2249	29949	1/11/1926	12/15/2005
	Trace elements	56	1173	7736	1/11/1926	12/15/2005
	Core field parameters	101	2794	5925	11/1/1942	12/15/2005
	Nutrients	63	1821	7214	1/11/1926	12/15/2005
	Microorganisms	17	552	952	11/23/1959	4/28/2003
Grand Canyon NP	Major ions	92	2106	28773	8/23/1925	12/30/2005
	Trace elements	53	1302	4573	8/23/1925	12/30/2005
	Core field parameters	100	1985	4919	7/1/1936	12/30/2005
	Nutrients	63	1612	5281	8/23/1925	12/30/2005
	Microorganisms	49	227	626	9/1/1981	10/24/1995
Hubbell Trading Post NHS	Major ions	4	20	175	9/1/1998	3/19/2003
	Trace elements	4	11	110	9/1/1998	3/19/2003
	Core field parameters	4	19	72	9/1/1998	3/19/2003
	Nutrients	4	13	98	9/1/1998	3/19/2003
	Microorganisms	4	8	16	9/21/1998	9/6/2000

Table 3. (continued) Number of sites, samples and results with sample period for all sites located within SCPN parks by parameter category for compiled historical water quality data from 1925 to 2005 (Brown 2008). Selected parameter categories shown include constituents of common concern for SCPN; all categories represent samples from the water column. Core field parameters include pH, SpC, DO, and water temperature.

Park	Parameter category	Number of sites	Number of samples	Number of results	Earliest sample	Latest sample
Mesa Verde NP	Major ions	31	72	744	10/21/1975	11/9/2005
	Trace elements	31	72	927	10/21/1975	11/9/2005
	Core field parameters	31	72	148	10/21/1975	11/9/2005
	Nutrients	28	68	150	10/21/1975	11/9/2005
	Microorganisms	14	31	59	9/11/1991	8/4/1998
Navajo NM	Major ions	3	9	167	9/11/2001	8/29/2002
	Trace elements	3	9	63	9/11/2001	8/29/2002
	Core field parameters	3	9	35	9/11/2001	8/29/2002
	Nutrients	3	9	72	9/11/2001	8/29/2002
	Microorganisms	3	9	26	9/11/2001	8/29/2002
Petrified Forest NP	Major ions	1	2	18	2/21/1985	10/26/2005
	Trace elements	1	3	41	2/21/1985	10/26/2005
	Core field parameters	1	2	8	2/21/1985	10/26/2005
	Nutrients	2	5	20	3/17/2005	-10/26/2005
	Microorganisms	1	2	48	2/21/1985	4/25/1985
Petroglyph NM	Major ions	1	2	10	8/9/1993	8/27/1993
	Trace elements	1	2	48	8/9/1993	8/27/1993
	Core field parameters	2	6	13	8/9/1993	8/27/1993
	Nutrients	1	2	12	8/9/1993	8/27/1993
	Microorganisms	2	3	5	8/9/1993	8/27/1993
Rainbow Bridge NM	Major ions	1	3	21	5/3/2005	11/30/2005
	Trace elements	1	3	75	5/3/2005	11/30/2005
	Core field parameters	1	3	18	5/3/2005	11/30/2005
	Nutrients	1	3	12	5/3/2005	11/30/2005
	Microorganisms	0	0	0	-	-
Salina Pueblo Missions NM	Major ions	4	15	60	11/28/2000	7/2/2001
	Trace elements	4	15	55	11/29/2000	7/2/2001
	Core field parameters	4	15	71	11/29/2000	7/2/2001
	Nutrients	0	0	0	-	-
	Microorganisms	0	0	0	-	-
Walnut Canyon NM	Major ions	1	2	33	9/18/2001	5/2/2002
	Trace elements	1	2	18	9/18/2001	5/2/2002
	Core field parameters	1	2	6	9/18/2001	5/2/2002
	Nutrients	1	1	11	9/18/2001	9/18/2001
	Microorganisms	1	1	3	9/18/2001	9/18/2001

Table 3. (continued) Number of sites, samples and results with sample period for all sites located within SCPN parks by parameter category for compiled historical water quality data from 1925 to 2005 (Brown 2008). Selected parameter categories shown include constituents of common concern for SCPN; all categories represent samples from the water column. Core field parameters include pH, SpC, DO, and water temperature.

Park	Parameter category	Number of sites	Number of samples	Number of results	Earliest sample	Latest sample
Wupatki NM	Major ions	3	6	99	10/21/1954	9/13/2002
	Trace elements	2	4	55	6/25/1979	9/13/2002
	Core field parameters	4	7	19	10/21/1954	9/13/2002
	Nutrients	3	5	27	10/21/1954	9/13/2002
	Microorganisms	2	3	9	10/23/2001	9/13/2002
Yucca House NM	Major ions	3	9	110	9/25/2002	11/3/2005
	Trace elements	3	8	120	9/25/2002	11/3/2005
	Core field parameters	3	9	41	9/25/2002	11/3/2005
	Nutrients	2	7	51	3/4/2003	11/3/2005
	Microorganisms	0	0	0	-	-

3.4 Summary of water quality standard exceedances in SCPN parks

Overall, few exceedances of state water quality standards have been identified in SCPN parks. Water quality data for BAND, CACH, CHCU, GLCA, and MEVE between 1925 and 2004 have been summarized in Brown 2008. The most common exceedances were for dissolved oxygen, water temperature, fecal coliforms, aluminum (dissolved), selenium (dissolved), copper (dissolved), and mercury. These exceedances occurred at multiple parks and in multiple samples. Other exceedances include pH, specific conductance, ammonia, beryllium, cadmium, iron, lead, silver, uranium, and gross alpha radioactivity; though these exceedances were uncommon or only occurred in one or two parks.

4 Sampling Design

4.1 Overview

The purpose of the SCPN water quality monitoring program is to collect and interpret water quality data to support NPS and network water quality objectives, including the determination of status and trends for selected water quality indicators of specific streams or springs. Priorities for monitoring include impaired streams or springs and relatively pristine waters. The target populations include wadeable streams and springs of ecologic or hydrologic significance.

The network selected streams and springs for water quality monitoring with input from park resource managers, SCPN staff, and other water quality specialists. The process included on-site interviews of staff from parks and other nearby agencies, a review of existing published and unpublished literature, and an extensive compilation and analysis of existing water quality data. The

results of this process are summarized in Appendices C and I of the SCPN Vital Signs Monitoring Plan (Thomas et al. 2006).

It was not feasible or practical to use a probability-based sampling design or to randomly select sampling sites because of budgetary constraints and logistical and time limitations imposed by conducting water quality monitoring activities across a broad geographic region, such as the Southern Colorado Plateau. However, within certain limits, water quality sampling will represent conditions in the watershed above the point of sample collection. Factors influencing the SCPN sampling design are presented in Table 4. Due to limitations imposed by the large geographic scale of the network, difficult site access, and the intermittent or ephemeral hydrologic regime of many SCPN streams, development of a design that would provide a general picture of regional water quality conditions was favored over a design built around intensive (monthly) sampling

Table 4. Planning considerations influencing SCPN water quality monitoring program sampling design.

Planning consideration	Influences on sampling design
Objectives	• Water sources that are included on the state 303(d) list, or have frequent exceedances for state standards are a high priority for monitoring. • Waters that can provide a representative indicator of the status and trends of water quality conditions for important water resources in the parks are also considered important.
Funding is very limited considering the number of parks and water resources that could potentially be monitored.	• SCPN must take advantage of existing monitoring conducted by the states, other federal agencies, and current monitoring by parks, and not duplicate these efforts. • Measures will generally be selected where the laboratory analysis is relatively inexpensive. For this reason, analysis for organic compounds (including pesticides), and radionuclides is not considered practical. • In most cases, even a major water body has only one sample site in a park. • Sites will be monitored 3 to 4 times per year, and visits will be spaced in order to capture as much seasonal variation as possible.
Access –SCPN parks are widely separated and some are very large, requiring many hours of travel to reach some of the more remote water sources.	• Accessible sample locations are often selected over those with unsafe or difficult access. Most sample sites will be accessible by vehicle or a less than two hour walk. • In some cases, water sources that are considered important will not be monitored due to the difficulty of access.
Availability of existing water quality data.	• Existing data was used to identify where exceedances occur, indicating degraded water quality. These sites are a high priority for monitoring. • It will be advantageous to select vital sign monitoring locations where data exists in order to build on the existing information base.
Absence of water quality data	• Filling water quality data gaps is a high priority.
Many of the sources of high levels of ions or trace element are believed to be natural.	• In some cases water quality exceedances may be due to natural conditions. NPS is interested in monitoring these conditions in order to be used effectively in any 303d listing or TMDL planning.
Sample timing and natural variability in some water quality characteristics due to seasonal variation and response to storm events.	• Samples will be collected 3 to 4 times per year at each monitoring site. Typically these sampling events will take place during periods of low / base flow. SCPN does not have the resources to safely and properly sample streams in high flow conditions.

of a very limited number of streams and springs. This approach will provide information that will help to determine compliance with the Clean Water Act (CWA).

When practical, SCPN water quality monitoring sites will be co-located with other network vital sign monitoring efforts, including aquatic macroinvertebrate, integrated riparian, and springs ecosystem monitoring.

Perennial waters were prioritized over ephemeral or intermittent water sources because these waters are the sources for which standards are commonly established and are most frequently monitored for compliance with CWA-based standards. Wadeable perennial streams were selected because costs and logistical challenges associated with properly collecting representative samples from large rivers, or from intermittent or ephemeral streams were prohibitive. However, water quality samples will be collected at ephemeral or intermittent streams in parks where these streams are management priorities.

4.2 Spatial design: Selecting streams and springs to monitor

While several large rivers flow through network parks, SCPN is not monitoring these non-wadeable rivers due to the cost, logistical considerations, and because other agencies are currently monitoring water quality in some of these rivers. Water bodies in the network that are not wadeable include the Animas River at Aztec Ruins National Monument, the Rio Grande at Bandelier National Monument, the Colorado River in Grand Canyon National Park, and the Colorado and San Juan Rivers in Glen Canyon National Recreation Area.

The hydrologic regime of rivers and streams can be categorized as perennial, intermittent, or ephemeral. Ephemeral streams flow only in direct response to precipitation, and their channels are above the water table at all times. Ephemeral streams are numerous in SCPN parks, usually small and often unnamed. For the most part, the network is not

monitoring ephemeral streams because it is difficult to time sample collection to periods of flow, and because they are frequently located in deep canyons, or in terrain that is difficult to access. However, ephemeral streams at Petroglyph National Monument have been proposed as monitoring sites because effects of the surrounding urban development are highly significant management issues for this monument.

For the most part, the sites that the network chose to monitor included springs and perennial or intermittent wadeable streams within priority target watersheds. Selection of sites was guided by: 1) water quality inventory and analysis reports prepared by the NPS-WRD, 2) a USGS summary and review of available water quality data from streams in SCPN parks (Brown 2008), 3) data collected by USGS during a Level 1 water quality inventory of streams in SCPN parks (Macy and Monroe 2006), and 4) results of water quality planning meetings with park staff. In addition, the following guidelines were used in selecting the water bodies where water quality monitoring sites would be located:

- 303(d) listed waters - where previous sampling indicates one or more parameters regularly approach or exceed established state water quality standards or recommended levels.
- Waters with demonstrated threat levels – where an analysis of existing data indicate that measured conditions regularly approach or exceed standards or recommended levels, but where the frequency of exceedances, or the quality of the database do not support a 303(d) listing.
- Pristine waters – where there is no direct impact of human activities (provides baseline data)
- Ecological significance – presence of unique species or species of concern
- Waters of management concern – where past sampling may not indicate constituent values of concern, but where anthropogenic activities indicate that contamination is a significant threat.

- Historical data – waters identified as important for which substantial historical water quality data is available.
- Data gaps – waters identified as important, but where little or no water quality information exists.
- Established monitoring – close to a site where complementary data is collected by SCPN (e.g., aquatic macroinvertebrate monitoring site) or another agency (e.g., streamflow gaging station).

SCPN has identified water quality monitoring sites on eight streams and 20 to 25 springs in network parks. In some cases, at intermittent or ephemeral streams, such as Chinle Wash at CACH, water quality samples will be collected on an opportunistic basis if flow is present at the time of a scheduled sample collection trip.

The NPS and other agencies and organizations are also conducting water quality monitoring in SCPN parks. This includes monitoring of the Colorado River and tributaries in and near GRCA by the USGS Grand Canyon Research and Monitoring Center, tributary streams in GRCA by NPS, and Lake Powell at GLCA by NPS.

4.3 Response design

4.3.1 Measurable attributes

The water quality attributes measured or sampled at each site are grouped by sample type (Table 5) for convenience of reporting and discussion. Collection of water quality core parameter data is required by NPS-WRD as the minimum suite of measure-

ments used as indicators of water quality. The core parameters were selected because they generally characterize water quality at a site for a relatively low cost. Major ions are used to determine alkalinity, and are useful in toxicity and transport models. Some of these ions are nutrients and trace elements necessary for biological activity and may be correlated with other water quality parameters. For more information about the NPS core water quality parameters see NPS-WRD (2002).

4.3.2 Data representativeness/sampling constraints

SCPN will adhere to NPS water quality monitoring guidelines and relevant USGS sampling standards to ensure that our data reasonably represent the target population and are comparable to regional USGS data. For example, we will use USGS methods (collector sites, cross-section checks, sampling from the centroid of flow, etc.) and will select sites upstream of bridges and culverts (as detailed in SOP #3), and choose random points from which to sample the midpoints and cross-sections upstream.

To help ensure inferences about the range of temporal variability for water quality data collected during site visits are appropriate, we will periodically deploy continuous water quality sondes. Data from these instruments will help us to understand seasonal and diurnal variability. These types of variability occur in many water quality parameters and will be discussed in greater detail in the Standard Operating Procedures (SOPs) included in this protocol.

Table 5. Water quality attributes measured at SCPN monitoring sites grouped by sample type.

Sample type	Attributes
Core field parameters	water temperature, pH, specific conductance (at 25°C), dissolved oxygen, turbidity and discharge
Bacteria	total coliforms and <i>E. coli</i>
Nutrients	Ammonia, nitrite, nitrate, orthophosphate
Major elements	acid neutralizing capacity, calcium, chloride, fluoride, magnesium, potassium, silica, sodium, sulfate, and total dissolved solids
Trace elements	aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, uranium, vanadium, and zinc

Spatial variability of water quality in streams can occur as a result of groundwater inflow or outflow; or as a result of contributions from tributary streams or springs. Where possible, SCPN will characterize spatial variability by collecting core water quality parameter data at multiple sites distributed along a stream. Sites will be located at approximately 0.5 mile intervals, or in such a way as to specifically bracket hydrologic zones. These ‘walk-through’ sample events will be conducted at the same group of sites along a stream once per year. The sample events will occur during base flow periods at the same time each year.

Obstacles that can make it challenging to collect representative samples include difficult or risky site access, particularly during storm events; and incomplete knowledge of storm event occurrence due to limited stream flow gage station coverage. Constraints imposed by laboratories, such as limits on the amount of time between sample collection and receipt by the laboratory, can be problematic when lengthy hikes to remote monitoring sites exceed the recommended sample hold time. Another impediment to collection of representative samples is that sampling sites located within park boundaries do not necessarily represent the entire watershed.

4.4 Revisit design

Water quality monitoring at streams in SCPN parks will occur 3 to 4 times each year. Springs will be visited approximately once every five to seven years. This design balances the need to sample every site with budget constraints that limit the number of site visits that can occur in each year.

4.4.1 Streams

To balance the need to minimize the annual cost of the program with the need for repeated collection of data at each stream water quality monitoring site, water quality samples will be collected from SCPN streams 3 to 4 times per year at intervals designed to capture the effects of seasonal variation. The number of times will depend on site characteristics, known water-quality conditions/

issues, and site-access considerations. Many streams in the network require multiple days of travel to obtain a single sample and some sites are not reasonably accessible year-round. This strategy will allow tracking of long-term trends while expanding the number of sites that can be monitored with limited resources.

4.4.2 Spring ecosystems

Spring ecosystems are important water features in many SCPN parks. These sources of water are critical to flora and fauna, as well as aesthetically appealing to park visitors. Monitoring these sites can be difficult because individual water sources, though often small, can be numerous, and may have diffuse discharge points that can be difficult to sample. SCPN’s spring water quality monitoring will be integrated with the network’s spring ecosystems monitoring. Biotic, physical, and water quality samples and data will be collected during site visits.

SCPN plans a two level approach to spring ecosystem monitoring. The first level of data collection at springs in SCPN parks will target sites where little or no data has been previously collected. Information collected during these initial visits will include site descriptions, establishment and location of photopoints, a census of riparian vegetation, and measurement of NPS core water quality parameters. The second level will include 20 to 25 springs in 9 parks (specific sites to be determined), that were selected for long-term monitoring by park and SCPN staff, based on unique or significant values. At each of these springs, hydrologic data will be collected 2 to 4 times per year. Data on vegetation and a suite of water quality parameters, including major elements, trace elements, nutrients, and micro-organisms, will be collected at regular five year intervals.

5 Field and Laboratory Methods

5.1 Standard Operating Procedures

Field and laboratory methods for water quality monitoring in SCPN parks are described in the Standard Operating Procedures (SOPs). SCPN water quality SOPs cover:

- field season preparations and water quality monitoring equipment
- hiring and training personnel
- site selection and documentation
- field and sampling methods
- sample preparation, shipping, and laboratory analysis
- data collection, entry, verification and data quality review
- data analysis and reporting,
- Quality Assurance Project Plan (QAPP) end-of-season procedures
- revisions to the protocol narrative and SOPs.

Procedures described in the SOPs are developed primarily from:

- USGS National Field Manual for the Collection of Water-Quality Data, variously dated
- manuals provided by manufacturers of the equipment used in SCPN water quality monitoring

5.2 Field methods

We will employ standard water quality sampling and analysis methods developed by the USGS and the USEPA. Regular attention to calibration and QA/QC methods is important to maintain high-quality data. Field measurements will include the NPS core water quality parameters (water temperature, pH, specific conductance, dissolved oxygen, turbidity and discharge). These parameters will be measured in situ with a current meter, a multi-parameter sonde, or individual water quality meters. Collection and enumeration of bacteria samples will be completed by

SCPN staff; and water chemistry samples for nutrients, major elements, and trace metals will be collected by SCPN staff and sent to a qualified contract laboratory for analysis.

A list of all parameters to be monitored, instrument/method used for analysis, agency responsible for analysis, and the corresponding SOPs for further information is provided in Table 6. Generally two SCPN staff will be present for the site visits and the total time to complete all tasks is 1 to 1.5 hours per site.

SCPN also conducts photopoint monitoring of water quality monitoring sites (see SOP #9).

5.3 Processing samples

Following sample collection, water quality samples will be processed and preserved in the field (see SOP #6). The goal of processing the samples is to remove particulate matter from the sample water and stabilize the samples in preparation for laboratory analysis. Samples are transferred either from a collection bottle or directly from the stream to appropriate bottles, depending upon analysis requirements. This transferring process often involves filtering and/or acidifying the samples. All sample bottles should be labeled and then securely packed for shipment to the contract laboratory. Appropriate paperwork must be completed (see SOP #11).

5.4 Laboratory processing of water quality samples

Quality and consistency of long-term monitoring data depends in part on the laboratory doing the analysis. SCPN selects only accredited laboratories that employ adequate QA/QC procedures. The analysis methods for each analyte should be specified and clarified with the laboratory staff before analyses begin. SCPN and laboratory staff will learn and follow the correct procedures for preparing samples (pretreatments, bottle sizes, types, and holding times) to ensure the accuracy of sample analyses.

To ensure that analyses are performed consistently, SCPN will utilize one contract

Table 6. List of parameters to be monitored at SCPN water quality monitoring sites with instruments used and agency conducting the analysis. USGS National Water Quality Laboratory is indicated as NWQL.

Parameters monitored	Instrument/method used	Analysis agency	Relevant SOP
Water temperature (at time of sample)	multi-parameter sonde	SCPN	5
Water temperature (long-term)	temperature loggers	SCPN	5
pH	multi-parameter sonde	SCPN	5
Specific conductance	multi-parameter sonde	SCPN	5
Dissolved oxygen	multi-parameter sonde	SCPN	5
Turbidity	portable turbidimeter	SCPN	5
Discharge	various	SCPN	5
Total coliforms and <i>E. coli</i>	IDEXX Quantitray 2000	SCPN	7
Nutrients	various, see SOP #8	NWQL	6, 8
Major elements	various, see SOP #8	NWQL	6, 8
Trace metals	various, see SOP #8	NWQL	6, 8

laboratory for analysis of water quality samples. The laboratory chosen must have passed independent state accreditations and approvals for all four states where SCPN collects water quality samples. It also must pass the federal National Environmental Laboratory Accreditation Program (NELAP, see <http://www.nelac-institute.org/>). These should include QA/QC checks such as blind-sample round-robin trial analyses of proficiency-test standards to see if the results the laboratory provides is similar to known (certified correct) ranges, in order to pass QC performance standards. The lab must undergo rigorous and independent checks to ensure that it can produce accurate and comparable results. The USGS National Water Quality Lab (NWQL) meets these criteria, but other contract laboratories may also be acceptable.

5.5 Quality assurance and quality control

Quality assurance consists of the planned and systematic actions that are necessary to provide adequate confidence, or assurance, that a project outcome optimally fulfills expectations. Quality control is the systematic evaluation of the various aspects of a project to ensure that the standards of quality are being met. Quality control involves specific tasks undertaken to determine the reliability of field and laboratory data. Together, quality assurance/quality control (QA/QC) is an

important part of a monitoring program.

The objective of QA/QC is to ensure that the data generated by a project are meaningful, representative, complete, precise, accurate, comparable, and scientifically defensible. It is a broad management concept for maintaining the ability to provide reliable information that requires the complete integration of the field activities of sample collection with laboratory analysis. Therefore, QA/QC incorporates peripheral, but essential operations, such as survey design, equipment preparation, maintenance tasks, data handling, and personnel training; it is summarized throughout this monitoring protocol.

5.6 Data comparability

Significant measures will be taken to ensure that SCPN water quality data is comparable with other data collected by other agencies (Table 7). The water quality project manager will coordinate with all entities involved in monitoring in network parks in order to optimize data sharing. Representatives from appropriate states will be contacted at a minimum on an annual basis to discuss data comparability issues and to distribute a metadata checklist. SOP #10 describes the QAPP and efforts to provide maximum data comparability with federal, state, and other monitoring agencies. This protocol provides the minimum standards and guidelines that SCPN should utilize, but we recommend

Table 7. Overview of SCPN Data Quality Assurance Project Plan. SCPN data quality assurance measures that address possible data quality issues.

Data Quality Issue	SCPN Data Quality Assurance measures
Sufficiency of metadata	Metadata requirements of NPSTORET are comprehensive, ensuring that methods, analyses and handling of both samples and data are documented in the same place as the data itself (including the attachment of the protocol and SOP documents themselves). Systematic verification of data in the database, as well as periodic review of stated procedures and included documentation (SOPs). The Protocol Narrative and SOPs will thoroughly document all field and laboratory methods, including QA/ QC measures.
Field methods	Standard USGS protocols will be followed, as explained in the SOPs. Documentation of equipment calibration frequency and acceptance criteria.
Lab methods	All laboratories analyzing SCPN samples will be certified for the parameter and analysis being conducted. All methods used for laboratory samples will follow Standard Methods using APHA/AWWA/WEF methods or comparable USEPA methods. Laboratory QC measures will include matrix spikes, method blanks, calibration standards, lab and field-duplicated samples.
Sensitivity	For lab parameters: Report Method Detection Limit (MDL) and Minimum Reporting Level (MRL). For field or "core" parameters: Quarterly collection of seven replicate samples or measurements in order to calculate the Alternative Measurement Sensitivity (AMS).
Precision	For field measurements: Calculating Relative Percent Differences (RPDs) for turbidity, AMS for sonde measurements. For lab measurements: Submit field replicates once per fifteen samples. Report the RPD.
Bias	Maintain consistent personnel and methodology where possible. Compare instrument measurements against known standards. Overlap* a minimum of, thirty (30) measurements when a method or equipment changes. Analyze such overlapping samples to determine the contribution of bias (if any) to any variance in the data. Control bias with the use and analysis of "blank" samples to determine contamination by methodology.
Version control	Ensure that data is clearly linked to the procedures used to collect data by accounting for previous data collection and processing procedures and explaining new methods and when they were implemented. This is critical to credible interpretation of data acquired after the implementation of changes.

*Overlap: old and new methods (i.e. old and new equipment, old and new personnel) will each be used to collect data from a site for a minimum number of times (a number of visits to different stations, or repeated measurements at a single site).

that more stringent criteria be used as well as methodologies that improve upon these minimum standards. The SOPs provide detail of procedures that will ensure collection of representative, comparable, accurate and precise data that can be shared statewide and nationwide, to the greatest extent possible.

One of the central ways to ensure the comparability of network data with other agency data is to follow basic information quality guidelines by integrating a high degree of transparency about data and methods used to generate the data, including quantifying precision, bias and sensitivity (SOP #10).

6 Data Management

Management of monitoring data involves procedures to collect, enter, verify, validate, document, archive, and distribute data. The project manager, data manager, and crew members ensure the integrity and security of the data during a given year by adhering to SOPs. Additional details are provided in the SCPN Data Management Plan (Tancreto and Hendrie 2006).

Additionally, the water quality component of the Natural Resource Challenge (NRC) requires that Vital Signs Networks archive all physical, chemical, and biological water quality data collected with NRC water quality funds in the National Park Service's STORET database maintained by the NPS-WRD.

Data management may be best understood as an ongoing process, as shown in Figure 3. Each step in the data management process is explained below.

6.1 Pre-season and pre-field preparations

The SCPN data manager ensures that project staff members have access to needed folders and files within the reserved workspace on the network file server (see SOP #13 in this protocol, and Appendix F in the SCPN data management plan). Automated back-up procedures are run on the network file server daily.

Prior to field trips, the project manager will work with the GIS specialist to ensure that target coordinates and any navigational waypoints, routes, tracks and backdrop maps are loaded on GPS units as needed. The project manager will also work with the data manager to ensure that the field laptop is fully updated and in working order.

6.2 Data collection

In the field discrete data are recorded on paper datasheets and continuous data are downloaded from data loggers onto the field laptop. For data recorded on paper, the

field crew is responsible for ensuring that all forms have been filled out completely and that the information on each form is logical and legible. Upon returning from each field trip, datasheets should be scanned to PDF files. If changes are subsequently made to paper datasheets, they should be re-scanned. The project manager is responsible for the safekeeping and filing of the datasheets. The scanned PDF files are archived by the data manager.

For continuous data collected digitally with data loggers, regular back-up files should be made in the field. Upon returning from each field trip, these data files should be transferred to the appropriate subfolder on the network file server (see SOP #13).

6.3 Data entry, verification, and validation

6.3.1 Data entry

Water quality monitoring data are managed with the SCPN water quality database, a relational database based on the NPS Inventory and Monitoring Program's Natural Resources Database Template (<http://science.nature.nps.gov/im/datamgmt/applications/template/index.cfm>).

The goal of data entry is to transfer the data from paper into the database with 100% accuracy. As soon as possible after a monitoring visit, the water quality monitoring data recorded on the paper forms should be entered into this database. Data entry should be completed by someone who participated in data collection or someone who is familiar with the project and data. Digital data files, either those collected in the field or those received from labs, are imported using tools that are built into the database (see SOP #14).

It is recommended that a backup copy of the database be created every time data are entered or modified. This ensures that the data can be recovered should irreversible errors or problems occur during the data entry session. Any time a revision of the protocol requires a revision to the database, a com-

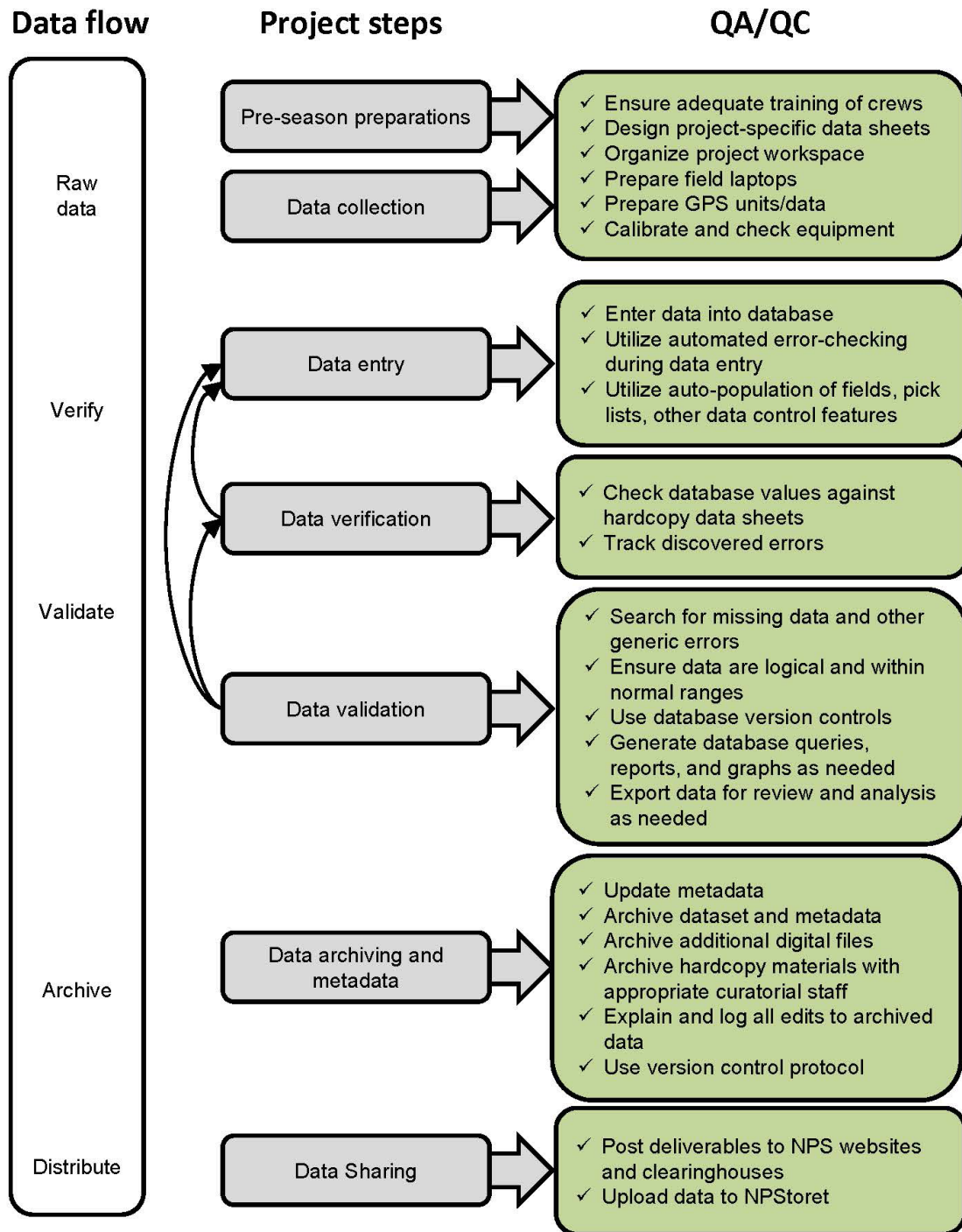


Figure 3. Data management steps and associated quality assurance/quality control (QA/QC) procedures that accompany the typical data flow in a Southern Colorado Plateau Network monitoring project.

plete copy of the database will be made and stored in an archive directory.

It is intended that the continuous data downloaded from data loggers will eventually be stored in Aquarius, a commercial program supplied by Aquatic Informatics (see SOP #15). Until then, continuous data are stored in Excel spreadsheets, and organized in the folder structure defined in SOP #13.

As data are entered in the database they are marked as uncertified. Once the data have gone through the processes of verification and validation, the data are marked as certified and are ready for use (see SOP #16).

6.3.2 Data verification

The data verification process ensures the data are accurately transferred from the data sheets to the database. The water quality database application incorporates quality assurance strategies to ensure data quality. The database design and the allowable value ranges assigned to individual fields within the data tables help to reduce the potential for data entry errors and/or the transcription of erroneously recorded data

SOP #16 describes this process in greater detail.

6.3.3 Data validation

Once verified the database will be validated to make sure the data make sense and are clean, complete and useful. The project manager and data management staff collectively validate a given year's dataset (see SOP #16). Data management staff will work closely with the project manager to provide any needed database queries, reports, graphs, or export file formats to assist with the overall validation.

Once approved, the annual dataset is marked as certified and is ready to be used.

6.4 Archiving data and metadata

Metadata is structured information about the content, quality, condition, and other characteristics of a given dataset. Metadata can also be easily cataloged making datasets

available to a broad range of potential users. Metadata for all protocol monitoring data will conform to Federal Geographic Data Committee standards (Federal Geographic Data Committee 1998).

Metadata are updated annually. Specific procedures for creating and posting the metadata record are provided in the SCPN Data Management Plan. Final metadata records are posted to the online NPS Integrated Resource Management Applications (IRMA, <https://irma.nps.gov/App>) satisfying requirements of Executive Order 12906 which states that data collected by federal agencies must be made available to the public (<http://www.archives.gov/federal-register/executive-orders/pdf/12906.pdf>).

Secure data archiving is essential for protecting data files from corruption (Tancreto and Hendrie 2006). Once the project dataset and metadata are considered final, the data manager will place a copy of the dataset and the metadata record into the appropriate folder within the archive directory on the network server. These archived files will be stored in read-only format.

Any editing of archived data must be documented in the edit log and accompanied by an explanation that includes pre-and post-edit data descriptions (Tessler and Gregson 1997). Datasheets can be reconciled to the database through the use of the edit log.

Prior to any major changes of a dataset, a copy is stored with the appropriate version number to allow for tracking changes over time. Each additional version will be assigned a sequentially higher number. Frequent users of the data are notified of the updates and provided with a copy of the most recent version.

Full metadata records are available through IRMA. Records for reports and other publications are created in the Data Store section (<https://irma.nps.gov/App/Reference/Search>) of IRMA. Digital report files, in PDF format, are then uploaded and linked to the IRMA record.

Any digital files associated with data analysis products and project reporting are to be archived in a similar fashion.

Digital materials can be made available to park curators upon request. Hard-copy materials (e.g., datasheets, field notebooks, and reports) are currently stored in the network office but will be moved to an NPS-approved repository for permanent storage.

6.5 Data Sharing

The NPS Water Resource Division (WRD) requires that all I&M water quality monitoring data be compatible with, and uploaded annually to the USEPA's STORET database. To facilitate this, the WRD maintains a Microsoft Access database tool, NPSTORET, which duplicates most of the data and table structures in USEPA STORET. An automated routine (see SOP #14) is built into the SCPN database to allow users to easily export data from the SCPN database which will be imported into NPSTORET. SCPN will transfer the network's version of NPSTORET to WRD each year following certification of data and completion of data summary reports.

Additional information on vital signs water quality data management and archiving, as well as a copy of NPSTORET, can be obtained at: <http://www.nature.nps.gov/water/vitalsigns/vitalsignsmgt.cfm>.

People requesting data should contact the data manager who will fulfill data requests (<http://science.nature.nps.gov/im/units/scpn/contact/contactUs.cfm>). Only validated datasets should be shared outside NPS. See the SPCN Data Management Plan for more details (Tancreto and Hendrie 2006).

7 Reporting and Analysis

Consistent reporting of data is critical for any monitoring program and provides park resource managers with information on the current status, and trends over time in the water quality of streams and springs. Two types of formal reports will be prepared regularly: data summaries and trend reports of water quality conditions.

7.1 Data summary reports

The primary purposes of SCPN data summary reports are to (1) document monitoring activities for the year and summarize the data collected (2) describe the current conditions of the resources sampled, and (3) provide data back to park managers in a timely way to increase data utility. An explanation of the significance of the results will be provided along with recommendations for special studies where indicated. The data summary reports will flag data values exceeding state standards, censor values below method detection limits, and identify anomalous values that may indicate the need for re-analyzing samples. The data summary report will also tabulate values exceeding, and approaching exceedance of standards (20% or less below the applicable standard). A description of SCPN data summary reports is provided in SOP #17; an example report is presented in Appendix E.

7.2 Trend reports

SCPN trend reports will provide statistical analysis of trend and change over time using monitoring data. Water quality data trend reports will provide comprehensive statistical analyses of continuous long-term data, and will be prepared approximately every five to ten years. The main objectives of trend reports are to report (1) patterns and trends in condition of resources being monitored, (2) new characteristics of resources, (3) correlations among related vital signs and environmental drivers/stressors, (4) the degree of change that can be detected by the current level of sampling, and (5) park and regional context to assist in interpreting

monitoring data.

Data summary and trend reports will be prepared by the SCPN water quality project manager, data manager, and water resources staff.

8 Personnel Requirements and Training

8.1 Roles and responsibilities

The SCPN program manager is responsible for the overall management and supervision of the network monitoring program. The 2016 Staffing Plan Revision calls for two interdisciplinary I&M Specialist (GS-408/1315-11) positions to manage water resource monitoring projects for SCPN, with one specialist managing riparian and springs monitoring projects, and the other managing water quality and aquatic macroinvertebrate monitoring projects.

The Water Quality/Aquatic Macroinvertebrate Specialist (GS-408/1315-11) will work with the program manager to coordinate the involvement of other network staff, including the data manager, the GIS specialist, and the quantitative ecologist (Table 8). S/he will hire water resource staff, and arrange field schedules and logistics. S/he may also oversee data collection and entry, and summarize and report water quality monitoring data. The specialist will often act as crew leader for field activities related to his/her specialty discipline. In some cases, other SCPN staff members or NAU cooperators may act as crew leaders on specific field trips. SOP #2 provides details on hiring and training field staffs.

In addition to the two interdisciplinary I&M specialists, the SCPN water resources staff will include one term hydrologic technician (GS-1316-07) and 2-4 staff members who work with the network through a cooperative agreement with Northern Arizona University (NAU). The water resources staff will conduct monitoring associated with this protocol and with the aquatic macroinvertebrate, integrated riparian, and spring ecosystems monitoring protocols. We estimate that field activities will take approximately 1 month per year, for each project followed by 1 month for data entry, verification/validation, and reporting.

The SCPN hydrologic technician (GS-7)

will be responsible for conducting hydrologic and water quality monitoring for SCPN parks, maintaining hydrologic and water quality monitoring equipment, and summarizing and preparing draft water quality monitoring reports. S(he) will also be responsible for assisting and sometimes leading aquatic macroinvertebrate monitoring trips.

8.2 Water resources staff qualifications

Competent, well-trained, and detail-oriented staff are essential for collecting credible, high-quality data in a long-term monitoring project. All water resources staff members should have good organizational skills, be able to perform detailed data collection procedures and have a background in the physical or biological sciences. The hydrologic technician must be knowledgeable in the fields of aquatic and riparian ecology, have a strong background in monitoring techniques, and be an effective leader and teacher of field skills. It is preferable for the hydrologic technician to have a Master's degree in a relevant discipline. At least one member of the water resources staff should be trained in surveying techniques and should have experience with total station and GPS survey equipment. Because many of the water-related monitoring sites are located in remote wilderness settings, field staff should be physically fit and experienced in backcountry hiking and camping. More detailed qualifications are provided in SOP #2.

8.3 Water resources staff training

Prior to the field season, all water resources staff members should read and become familiar with the SCPN water quality monitoring protocol. Training is an essential component of pre-season preparation and is crucial for maintaining data quality. Because year-to-year consistency in implementing the protocol will ultimately determine the quality of the monitoring data and affect the likelihood of accurately detecting trends in water quality condition, the need for high-

Table 8. Positions and key roles and responsibilities of staff who implement field-based water quality monitoring in the Southern Colorado Plateau Network.

Position	Roles and responsibilities
Program manager	The program manager is responsible for the overall management and supervision of the program. Duties include developing the process for selecting indicators, overseeing the development and testing of monitoring protocols; hiring and supervising network staff; managing the implementation of monitoring projects; and ensuring that resulting data are appropriately analyzed, reported, and made available for park planning and management.
Project manager	The project manager is the Interdisciplinary I&M Specialist (GS-408/1315-11), who is responsible for implementing the water quality and aquatic macroinvertebrate monitoring projects. Duties include working collaboratively with network park staff to understand management issues and information needs regarding water quality, hiring and training field staff, obtaining all necessary research permits, and completing scheduled data analysis, reporting, and integration/interpretation of monitoring results. The project manager works closely with the data manager and the hydrologic technician to ensure that high-quality standards are achieved and maintained in the collection, processing, and analysis of integrated riparian data. The project manager will serve as the point of contact concerning data, and will work to establish partnerships with state and federal agencies and others involved in water quality monitoring.
Data manager	The data manager is responsible for the information and data stewardship of the water quality monitoring project. The data manager designs databases, writes the data management plan and protocols, and works with the project manager and network staff to ensure that datasets are fully documented, validated, and certified. The data manager, in collaboration with the project manager and hydrologic technician, develops data entry forms and other database features as part of quality assurance, and automates report generation. The project manager and data manager share the responsibility of preparing data for analysis. The data manager populates NPS service-wide databases, maintains digital document libraries, and maintains the network website.
GIS specialist	The GIS specialist is responsible for managing the spatial data and providing GIS support to the water quality monitoring project. Duties include managing, documenting and distributing spatial data from the monitoring project, and maintaining a library of relevant park spatial data.
Quantitative ecologist	The quantitative ecologist works with the program manager and project manager to develop spatial and temporal sampling designs for the project and develop sound statistical approaches to analyzing monitoring data, and provides analytical support to the project.
Hydrologic technician	The hydrologic technician (NPS GS-7) conducts hydrologic and water quality monitoring for network parks. Responsibilities include operating hydrologic and water quality monitoring equipment, organizing hydrologic and water quality data, and scheduling and making logistical arrangements for sampling trips. The hydrologic technician will also prepare preliminary technical reports of monitoring results.
Water resources staff	In addition to the interdisciplinary I&M specialist (henceforth referred to as the water quality project manager) and the hydrologic technician, the water resources staff will typically consist of 2–4 members with responsibilities for field data collection and laboratory processing of samples, equipment maintenance, ordering supplies, and data entry and verification.

quality training cannot be overemphasized. At minimum, one or two staff members should receive formal training in water quality sampling methods. This could be accomplished by contracting with a hydrologist familiar with the methods used in this protocol or by sending staff members to training offered by USGS or one of the state agencies. The hydrologic technician will then train other staff members and hold field practice sessions to develop individual skills.

8.4 Safety

Director’s Order #50B, Occupational Safety and Health Program, mandates that specific employee safety and health related activities be conducted within National Park Service worksites. The objective of the NPS Occupational Safety and Health Program is to “improve the management and cost-effectiveness of operations” by

- reducing the frequency and severity of accidents and losses for employees and

visitors

- providing a safe and healthful work environment for employees
- providing for the safety and health of the public (visitors) by protecting them from recognized hazards in NPS operations, on NPS lands and in NPS facilities
- protecting NPS property and private property from accidental damage or loss associated with NPS activities
- including considerations of safety and health as an integral part of every operation (NPS 2008)

SCPN is committed to providing safe working conditions for its employees and cooperators. The network does this by

- providing thorough training so that employees have the knowledge, skills and abilities to perform their jobs safely
- providing training for employees and supervisors to recognize unsafe and unhealthful work practices and conditions
- ensuring that employees know and follow safety work rules and procedures
- ensuring that all vehicles and equipment are in good working condition
- convening a safety committee to review any incidents that may occur and make recommendations to prevent their recurrence
- developing a network safety plan

8.4.1 Safety plans

SCPN has prepared a Field Safety Plan that specifically addresses conditions that water resources, integrated upland, and bird monitoring crews may encounter in the course of conducting fieldwork (Southern Colorado Plateau Network 2013). All field staff should thoroughly review the safety procedures in this plan at the beginning of every field season. NAU staff must also review the NAU Field Safety Guide and the Chemical Hygiene Plan and Laboratory Safety.

8.4.2 Safety training

It is recommended that crew leaders and field staff undergo Wilderness First Aid and Wilderness First Responder training, which should also include cardiopulmonary resuscitation (CPR) training, prior to the start of the season.

8.4.3 Project-specific information

In addition, the field crew should familiarize themselves with the backcountry guidelines, job hazard analyses, and emergency protocols for the parks in which they work, as applicable. It is the responsibility of network staff and cooperating employees to be aware of project-specific safety concerns and to take the necessary safety precautions.

9 Operational Requirements

9.1 Annual workload and field schedule

The water quality project manager and the hydrologic technician will oversee and implement the water quality monitoring program and the preparation of annual data summary reports and periodic trend reports. The project manager will also represent the network at a variety of local, regional, and national aquatic ecology, water quality, and related forums. Several NPS and NAU staff, including the water resources lead technician, will support the water quality monitoring program (see Section 8, Personnel Requirements and Training, for details).

The SCPN water resources field staff is responsible for field data collection, sample processing, and data entry and verification. Field staff also help prepare annual data summary reports for the network's four water-related monitoring projects. Approximately 25% of the water resources staff's time will be dedicated to the water quality monitoring project. Preparation for the field season must begin well in advance of the pre-season training session. Appendix A provides a yearly project task list that identifies each task by project stage, indicates who is responsible, and establishes the timing for its execution.

Water quality samples will be collected 4 times each year from selected streams, and once every 5 years from selected springs in SCPN parks. Typically, two people are required to complete the field monitoring portion of the protocol. Because SCPN parks

are widely dispersed and many monitoring sites are in remote areas, it will take one to two field days (including travel) to complete the fieldwork for one site.

Water quality samples will be processed in the field, if necessary and if sufficient time is available, or in the laboratory immediately following the field trip. All sample analysis will be completed by a qualified contract laboratory. Laboratory sample analysis will take approximately 4–6 months. The contract laboratory shall provide data in a format compatible with network databases.

Staff will enter data into the appropriate database throughout the field season and should be able to complete data entry within one or two weeks after completing their last sampling event of the spring and fall sampling season. Detailed data entry instructions are provided in SOP #14.

9.2 Facility and equipment needs

The SCPN water quality monitoring program will be based out of the program office in Flagstaff, Arizona. SCPN will acquire and maintain all equipment required to implement this monitoring protocol. Appendix F provides a complete list of the necessary field equipment. There will be an ongoing need for equipment maintenance, repair and/or replacement due to normal wear and tear. Most equipment will be specific to the water quality monitoring program; however, some equipment will also be used for the integrated riparian, aquatic macroinvertebrate, and spring ecosystem monitoring projects.

Accommodations for field staff when traveling will include park housing when available, vehicle-accessible campgrounds in or

Table 9. SCPN water quality monitoring project budget (estimate).

Budget item	Annual cost
NAU Water Resources field crew (25%)	\$12,000 to \$15,000
Equipment and supplies	\$8,000 to \$15,000
Travel	\$5,000 to 7,000
Laboratory	\$30,000 to \$35,000
Total	\$55,000 to \$72,000

near parks, or overnight camping at remote, primitive locations.

9.3 Budget considerations

An estimated budget for conducting water quality monitoring in SPCN parks is presented in Table 9. Start-up field equipment costs were approximately \$25,000. After the first year, we anticipate that the cost of field equipment replacement and supplies will decrease. Laboratory processing of water quality samples by a qualified contract laboratory will vary depending upon the number of sites sampled, the constituents analyzed, and the laboratory used.

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11 Revision history

Provide the following information for each revision made to the SCPN Water Quality Monitoring Protocol Narrative.

New version:

SCPN_WATER_QUALITY_Narrative_YYYYMMDD

Date:

Author:

Sections affected:

Changes & reasons:

Appendix A

Yearly Project Task List

This appendix identifies each water quality monitoring task by project stage, indicates who is responsible, and establishes the timing for its execution.

Project stage	Task description	Responsibility	Timing
Hiring and training the field crew	Prepare and release announcements for open technician positions	project manager	Jan–Feb
	Field crew training		
	Safety	hydrologic technician	
	Water quality sampling procedures	hydrologic technician	
	Database training	data manager	
Administration	Submit/renew research permit application	project manager	Nov–Mar
	Update agreement with contract lab	project manager	Mar–May
	Renew communications equipment - satellite phone minutes, SPOT activation	project manager	Mar–May
	Notify park contacts of monitoring schedule/itinerary, obtain backcountry permits, housing, keys	project manager	2 weeks prior to trip; 4 weeks prior for GRCA.
Planning	Meet to recap past year, discuss the upcoming year, and document any needed changes to field sampling protocols or the working database	hydrologic technician, field crew and project manager	Nov–Dec
	Plan field schedule and logistics	project manager and hydrologic technician	Nov–Dec
	Prepare/update site folders, include site photographs and previous trip reports.	hydrologic technician	prior to each trip
	Ensure that project workspace is ready for use and implement working database copy	data manager	continuously
	Inventory equipment and supplies	hydrologic technician	Mar, Aug
	Order equipment and supplies	hydrologic technician	1 month prior to trip
Field activities	Brief crew on operations, field methods, gear needs, etc.	hydrologic technician	Before each trip
	Check in with park contacts	hydrologic technician	as required by park
	Check in with project manager	hydrologic technician	daily when in backcountry
	Collect field observations/samples	field crew	4 times per year per site
	Review datasheets after each sampling day	crew	daily
	Ship samples	hydrologic technician	depends on sample type

Project stage	Task description	Responsibility	Timing
Data download, entry and verification	Write trip report	hydrologic technician	after each field trip
	Download water quality data from instruments or laptop.	water resources crew	as soon as possible after each field trip
	Download and organize digital images.	water resources crew	as soon as possible after each field trip
	Upload laboratory data into database.	water resources crew	as soon as possible after data is received
	Enter data into database.	water resources crew	as soon as possible after each field trip
Data management	Verify database.	water resources crew	Apr–Jun
	Upload working data into master project database and local NPSTORE ^a database.	data manager	yearly
	Create/update project metadata records.	data manager and project manager	yearly
	Certify database.	data manager	yearly
	Notify project manager of validated and verified data ready for analysis and reporting.	data manager	after data verification
	Export automated summary queries and reports from database.	data manager	after data verification
	Complete data processing steps.	field crew	after data verification
Data summary and reporting	Prepare draft annual reports; complete internal review.	hydrologic technician, project manager, and editors	May–Aug
	Generate report-quality map output for reports.	GIS specialist	May–Aug
	Finalize, format, and submit data summary reports to NPS publications where each report will be assigned a series number.	hydrologic technician, project manager, and editor	Jul–Aug
Product delivery	Notify park management that reports are complete and available.	project manager and editor	Aug–Sept
	Upload completed report to IRMA ^b .	editor	Aug–Sept
	Upload report to SCPN website (or create a link to the report in IRMA).	data manager	Aug–Sept
	Submit metadata to NPS IRMA.	data manager	yearly
	Send data to NPSTORET.	data manager	yearly
Archiving			After data has been entered to database and summary reports have been completed
	Archive all digital and hardcopy products.	project manager and data manager	
	Review, clean up and store and/or dispose of project files according to NPS Director's Order #11D ^c .	project manager and editor	Oct–Dec
Annual wrap-up	Inventory equipment and supplies.	hydrologic technician	winter
	Meet to discuss recent field season and any needed changes to protocols, database, or analysis and reporting procedures.	project manager, hydrologic technician, data manager, GIS specialist and program manager	winter

Project stage	Task description	Responsibility	Timing
	a NPSTORET is a complete water quality database management system that allows users to enter information about their water quality monitoring Projects, Stations, Metadata, and Results in a Microsoft Access database b The Integrated Resource Management Applications (IRMA) Portal provides access to National Park Service applications that manage and deliver resource information to parks, partners and the public. (https://irma.nps.gov/Portal)c NPS Director's Order 11D provides a schedule indicating the amount of time that the various kinds of records should be retained. Available at: https://www.nps.gov/policy/DOrders/DO_11D.pdf.		

Appendix B

Southern Colorado Plateau Network Water Quality Monitoring Sites

Table B-1 Streams

Park	Site name	Northing ¹	Easting ¹	Zone	Elevation (m) ¹	Site code
BAND	Capulin Creek at Base Camp Gaging Station	3958026	379713	13	1904	BANDCAP01
BAND	Capulin Creek above Painted Cave ²	3955457	380300	13	1791	BANDCAP02
BAND	Rito de los Frijoles near Visitor Center	3959889	385363	13	1840	BANDRIT01
BAND	Rito de los Frijoles at Upper Crossing	3964316	377109	13	2151	BANDRIT02
CACH	Black Rock Canyon below Confluence of East and West Forks ²	4002998	651566	12	2071	CACHBLA01
CACH	Chinle Wash at Chinle ²	4002062	631525	12	1689	CACHCHI01
CACH	Tsaile Creek below Tsaile Dam	4015393	660576	12	2125	CACHTSA01
GLCA	Coyote Gulch above Crack-in-the-Wall Trail	4142251	500945	12	1147	GLCACOY01
GLCA	Escalante River at Coyote Gulch	4142320	501698	12	1129	GLCAESC02
GRCA	Bright Angel Creek below First Footbridge ²	3998996	403192	12	945	GRCABRI01
GRCA	Bright Angel Creek near Colorado River	3995562	401526	12	752	GRCABRI02
GRCA	Garden Creek below Tonto Trail	3993992	399029	12	1085	GRCAGAR01
GRCA	Hermit Creek below Tonto Trail ²	3993801	390832	12	867	GRCAHER01
MEVE	Mancos River at Gage	4126163	734375	12	1933	MEVEMAN01
MEVE	Mancos River above Downstream Boundary ²	4122566	735878	12	1882	MEVEMAN02

¹ Horizontal coordinates are reported in Universal Transverse Mercator (UTM) Projection, North American Datum of 1983 (NAD 83). Vertical coordinates are referenced to the North American Vertical Datum of 1988 (NAVD 88).

² Only core parameter measurements taken at this site.

Table B-2 Springs

Park	Spring
CACH	Wild Cherry Cattail Spring
CACH	Tsaile Spring
CACH	Many Cherry Spring
CACH	Twin Trail Canyon Spring
CACH	Bare Rock Hanging Garden
ELMO	Historic Pool
GLCA	TBD
GLCA	TBD
GLCA	TBD
GLCA	TBD
GLCA	TBD
MEVE	Fewkes Canyon Spring #4
MEVE	Park Entrance Spring
MEVE	Spruce Tree House Spring
MEVE	TBD
MEVE	TBD
NAVA	Betatakin Ruin Spring
SAPU	Abo Spring
SAPU	Canon Sapato Spring
WACA	Cherry Pool
WUPA	Heiser Spring
YUHO	Aztec Spring

Appendix C

Decontamination Considerations and Procedures

1 Introduction

Invasive species are alien species that can cause environmental or economic harm when they enter into an ecosystem. They are one of the leading causes of species extinction and biodiversity loss in aquatic systems worldwide (US EPA 2012). Invasive species can affect aquatic ecosystems by reducing the populations of native species, modifying water tables, and by altering the ecosystems in numerous other ways. These effects can also impact recreational and commercial activities dependent on aquatic ecosystems.

Although invasive aquatic species are not currently a serious concern for most of the streams and springs in SCPN parks, several species are known to exist in the larger water bodies of the Colorado Plateau. Therefore, SCPN takes great care to minimize the possibility of spreading invasive species by following the procedures described in this appendix whenever personnel or equipment make contact with ambient (stream, spring, lake, etc.) water, and are moving between sites on a water body or to a different water body. By adhering to these procedures, SCPN water resources staff will help to reduce or prevent the spread of aquatic diseases and invasive species while conducting routine field procedures.

2 Invasive species and decontamination procedures

The insert on pages C-2 to C-3 provides information about some of the invasive aquatic species known to be present on the Colorado Plateau and the use of decontamination procedures to prevent their spread.

Invasive Species on the Colorado Plateau

(from: Aquatic Nuisance Species Task Force 2014)

New Zealand Mud Snail (*Potamopyrgus antipodarum*)

Identification. New Zealand mudsnails are small (3 to 6 mm or 1/8 inch) snails that have brown or black cone-shaped shells with five whorls. Where dense populations have developed, they often look like BB's scattered on the river's bottom. Taxonomically, New Zealand mud snails are in the snail family Hydrobiidae.

Habitat. New Zealand mud snails appear to prefer flowing water habitats with stable flows. Springs, spring creeks, and river sections downstream from dams are all places where they thrive. They are most typically found on larger cobble substrates or on pieces of wood. Routine aquatic invertebrate monitoring may not detect them as they stick well to rocks and they do not tend to float downstream very far. Pick up and evaluate individual softball sized rocks and larger sticks.

Densities and competition with native species. This snail has the ability to reproduce quickly and mass in high densities. When snails become as dense as one-half million per square, they become a cause for concern in western streams. One fear is that the mudsnails will impact the food chain of native trout and alter the physical characteristics of the streams.

Research is needed to determine the impacts of large populations of mudsnails



on the native fauna, such as aquatic insects and native snails, and on the physical environment.

Ability to survive in variable conditions. Mudsnails are able to withstand dessication, a variety of temperature regimes, and are small enough that many types of water users (anglers, swimmers, picnickers, pets) could inadvertently be the mechanism for interbasin transfer of this nuisance species. The rapid spread of the mudsnail throughout the Yellowstone watershed may have been assisted by human transport. Because the mudsnails reproduce asexually, it only takes one individual to become introduced into new water to make an impact. Also, the mudsnails can readily attach themselves to boots and waders.

Rock Snot (*Didymosphenia geminata*)

Identification. *Didymosphenia geminata* (Didymo) is a single-celled alga that grows on stalks and forms large colonies. The stalks are responsible for the negative impacts of this species and are composed

of a complex slimy substance. Colonies of cells are visible as white to light brown tufts attached to rocks. As the colonies develop, they smother rocks and trap fine sediment.

<i>Habitat.</i> Didymo tends to form excessive mats in • low, stable flow • water 3–6 feet deep • moderate to swift current • below outlets of lakes and reservoirs • sunny, open streams <i>Ecological impact.</i> Didymo impacts other stream elements, and impacts are greater when large mats are present: • aquatic larval insects (caddisflies, stoneflies, and mayflies) decline • other aquatic larval insects increase (midge larvae and worms) increase	
Whirling Disease <i>Identification.</i> Whirling disease is the descriptive side effect produced by a complex relationship involving a non-native parasite and a common aquatic worm that exclusively impacts coldwater sportfish, specifically trout and salmon. The parasite becomes engulfed by a tubifex worm, which acts as an intermediate host for the parasite. Eventually, this relationship produces a new free-floating life phase of the parasite that attaches itself to trout and salmon. After coming into contact with the host fish, the parasite penetrates the head and spinal cartilage of fingerling trout where it multiplies very rapidly, putting pressure on the organ of equilibrium. This causes the fish to swim erratically (whirl) and have difficulty feeding and avoiding predators. It is this whirling effect that has provided the name for disease that has significantly impacted our coldwater fishery resources. <i>Ecological Impact.</i> Whirling disease has devastating impacts on coldwater fisheries in North America. All species of trout and salmon may be susceptible to whirling disease. Other members of the trout and salmon family, such as mountain whitefish are also at risk. Rainbow trout and cut-throat trout appear to be more susceptible than other trout species. Brown trout become infected with the parasite, but they appear to have immunity to the infection and have not been as greatly impacted as rainbow trout. Scientific studies have demonstrated that grayling and bull trout are very resistant to infection. However, regardless of species, when each infected fish dies, many thousands to millions of the parasite spores are released to the water. These parasitic spores are virtually indestructible -- they can withstand freezing and desiccation, and can survive in a stream for 20 to 30 years.	
General procedures for preventing the spread of aquatic invasive species (from: Aquatic Nuisance Species Task Force 2014) Invasive aquatic species can be introduced into bodies of water in numerous ways, many of which involve the species “hitchhiking” on equipment, clothing or vessels as they are moved from one body of water to another. Follow this general procedure every time you come in contact with any body of water, whether or not there are known invasive species present, because it is always possible that an invasive species has been introduced, but has not yet been discovered.	

1. Before leaving any body of water, examine all your equipment, boats, trailers, clothing, boots, buckets, etc and remove any invasive species present. Do not transport them to your home or to another water body.

- Remove any visible plants, fish or animals.
- Remove mud and dirt and plant fragments since they may also contain a hitchhiker. The larvae (immature form) of an animal can be so tiny that you cannot see it.

2. Much of the recreational equipment used in water contains many areas where water can collect and potentially harbor aquatic hitchhikers.

- Eliminate all water from every conceivable item before you leave the area you are visiting.
- Remove water from motors, jet drives, live wells, boat hulls, scuba tanks and regulators, boots, waders, bait buckets, seaplane floats, swimming floats.
- Once water is eliminated, follow the cleaning instructions listed below.

3. Clean and dry anything that came into contact with the water, including boats, trailers, equipment, dogs, boots, clothing, etc.

Procedures for cleaning hard-to-treat equipment that can't be exposed to hot water:

- Dip equipment into 100% vinegar for 20 minutes to kill harmful aquatic species.
- Use a 1 % table salt solution for 24 hours. For the following quantities of water use the indicated amounts of salt:

Water (gals)	5	10	25	50	100
Salt (cups)	2/3	1 1/4	3	6 1/4	12 2/3

- If hot water is not available, spray equipment such as boats, motors, trailers, anchors, decoys, floats, nets, with high-pressure water.
- DRY equipment. If possible, allow five days of drying time before entering new waters.

Appendix D

Water Quality Monitoring Database Documentation

1 Purpose

This appendix documents the Water Quality Monitoring database for the Southern Colorado Plateau Network (SCPN). Microsoft Access is the primary software used to manage data, while SQL Server is increasingly used to host and visualize the data.

2 Water Quality Monitoring Database: Data model

The Water Quality database employs a single front-end/dual-back-end configuration. The front-end file contains the forms, queries, modules, macros, and reports; the two back-end files contain the data tables.

This front-end/back-end configuration allows for continual improvements to the user interface (i.e., the various forms and queries for getting data into and out of the database) without requiring duplication or modification of the underlying data tables.

The primary back-end contains all the actual water quality related data; the secondary back-end contains shipping information for the samples sent to water quality labs. Both back-ends must be present for the front-end to function properly.

3 Documentation of database tables

This section describes the tables for the two back-end databases utilized by the SCPN Water Quality Monitoring Program.

3.1 Primary back-end database tables

This section describes the tables contained within the primary back-end database. Figure D-1 shows the relationships between tables in the primary database. The database is based on the National Park Service Natural Resources Database Template (NRDT) Version 3 and contains all the actual water quality data, including field visit information, field data, and testing the results returned from water samples sent to water quality labs. The Event Table (tbl_events) is the primary driver in this database. One Event relates to one water quality sampling field trip. Where sampling locations are close to each other, more than one event can occur on the same day, but each location can only have one event on one day. Where sampling locations are far from the road, and especially when such remote locations are in extremely warm areas, one Event can cross two days, as the field crews hike and sample at night.

3.1.1 Table: tbl_Bact_Inc_Temp

Stores temperature data related to the incubator used to grow bacteria from water quality samples taken in the field. It is used to track situations or actions that could affect the temperature in the incubator. This table connects to an Event via the Bacteria Table (tbl_Bacteria) in a one-to-many relationship.

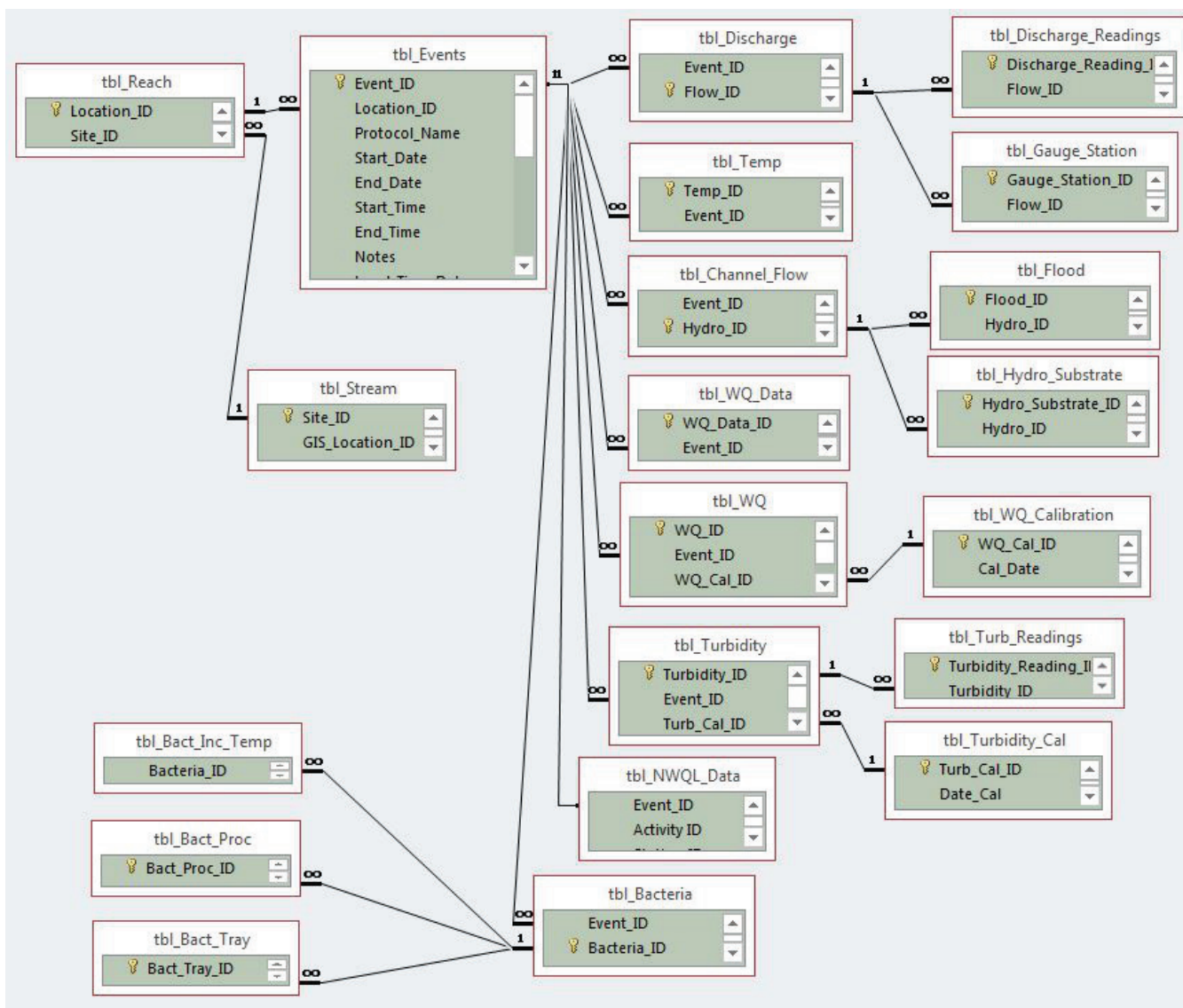


Figure D-1. Data model for the primary (water quality data) back-end for the SCPN Water Quality monitoring program.

Table 3.1.1.1. tbl_Bact_Inc_Temp

Field name	Field type	Field description
Bacteria_ID	Replication ID	Foreign key - links to the Bacteria Table (tbl_Bacteria)
Event_Action	Text	Description of the event that occurred and/or action taken
Event_Date	Date/Time	Date of the event or action taken
Event_Time	Date/Time	Time of the event or action taken (in 12 hour format)
Temp	Floating-point	Temperature in degrees Celsius

3.1.2 Table: tbl_Bact_Proc

Stores procedural information for field bacteria testing, such as type of bacteria and coliform trays used. This table connects to an Event via the Bacteria Table (tbl_Bacteria) in a one-to-many relationship.

Table 3.1.2. tbl_Bact_Proc

Field name	Field type	Field description
Bact_Proc_ID	Replication ID	Primary key
Bacteria_ID	Replication ID	Foreign key - links to the Bacteria Table (tbl_Bacteria)
WQ_Collect_Vessel	Text	Idexx 120 mL collection vessel
WQ_Collect_Lot	Text	Collection vessel lot number
WQ_Collect_Expire	Date/Time	Collection vessel expiration date
WQ_Bact_Tray	Text	Type of bacteria tray used
WQ_Bact_Tray_Lot	Text	Bacteria tray lot number
WQ_Bact_Tray_Expire	Date/Time	Bacteria tray expiration date
WQ_Coliform	Text	Type of coliform tray used
WQ_Coliform_Lot	Text	Coliform tray lot number
WQ_Coliform_Expire	Date/Time	Coliform tray expiration date

3.1.3 Table: tbl_Bact_Tray

Stores tray specific information for each bacteria tray used when testing for bacteria in water samples. This table connects to an Event via the Bacteria Table (tbl_Bacteria) in a one-to-many relationship.

Table 3.1.3. tbl_Bact_Tray

Field name	Field type	Field description
Bact_Tray_ID	Replication ID	Primary key
Bacteria_ID	Replication ID	Foreign key - links to the Bacteria Table (tbl_Bacteria)
Tray	Integer	Tray number this table entry pertains to
TC_Large_Wells	Integer	Number of large wells on the total coliform tray that contained bacteria growth (range: 0-49)
TC_Small_Wells	Integer	Number of large wells on the total coliform tray that contained bacteria growth (range: 0-48)
Replicate	Text	Indicates whether this tray is a blank, a primary sample, or a replicate
EC_Large_Wells	Integer	Number of large wells on the <i>E. coli</i> coliform tray that contained bacteria growth (range: 0-49)
EC_Small_Wells	Integer	Number of large wells on the <i>E. coli</i> coliform tray that contained bacteria growth (range: 0-48)
Total_Coliform	Text	Total coliform derived from a bacteria chart using the number of large and small wells
Total_E_Coli	Text	Total <i>E. coli</i> derived from a bacteria chart using the number of large and small wells

3.1.4 Table: tbl_Bacteria

Stores all the basic bacteria testing data for each Event where bacteria was tested. This table connects to an Event by linking directly to the Event Table (tbl_Events) in a one-to-many relationship.

Table 3.1.4. tbl_Bacteria

Field name	Field type	Field description
Bacteria_ID	Replication ID	Primary key
Event_ID	Replication ID	Foreign key - links to the Event Table (tbl_Events)
End_Date	Date/Time	Incubation end date
Start_Time	Date/Time	Incubation start time (in 24 hour format)
End_Time	Date/Time	Incubation end time (in 24 hour format)
Make_Model	Text	Incubator Make/Model
Temp_Logged	Text	Incubator temperature logged during incubation
Temp_Logger	Text	Incubator temperature logger make/model
Logger_SN	Text	Incubator temperature logger serial number
Logger_File_Name	Text	File name for the data uploaded from the incubator temperature logger
Comments	Text	Notes and comments
Processed_By	Text	Name of the person who processed the bacteria tray well count
Read_By	Text	Name of the person who read the bacteria tray well count

3.1.5 Table: tbl_Channel_Flow

Stores the stream channel and flow conditions at the time of the field visit. This table connects to an Event by linking directly to the Event Table (tbl_Events) in a one-to-many relationship.

Table 3.1.5. tbl_Channel_Flow

Field name	Field type	Field description
Hydro_ID	Replication ID	Primary key
Event_ID	Replication ID	Foreign key - links to the Event Table (tbl_Events)
Stream_Channel	Text	Describes the stream channel (picklist options: pool, riffle, open channel, braided, or backwater)
Flow_StreamColor	Text	Describes the water color (picklist options: clear, milky, foamy, tea, muddy, green, scum/odor, or other)
StreamColor_Other_Desc	Text	Additional descriptive text when a stream color of "other" has been selected
Flow_mixing	Text	Describes the flow mixing (picklist options: excellent, good, fair, or poor)
Flow_severity	Text	Describes the flow severity (picklist options: dry, no flow, low, normal, above normal, or flood)
Flow_hydro	Text	Describes the location on the hydrograph the flow would be located on (picklist options: base, rising, peak, or falling)
Ice_Thickness	Floating-point	Average ice thickness in centimeters
Ice_Cover	Integer	Percent of the stream surface covered in ice
Comments	Text	Comments about stream channel or flow conditions

3.1.6 Table: tbl_Discharge

Stores stream discharge measurement information. This table connects to an Event by linking directly to the Event Table (tbl_Events) in a one-to-many relationship.

Table 3.1.6. tbl_Discharge

Field name	Field type	Field description
Flow_ID	Replication ID	Primary key
Event_ID	Replication ID	Foreign key - links to the Event Table (tbl_Events)
Observer	Text	Name of the person who performed discharge measuring
Time_Start	Date/Time	Time discharge measuring started (in 24 hour format)
Time_end	Date/Time	Time discharge measuring ended (note: it is possible for this time to cross midnight, as some streams in hot locations are sampled at night) (in 24 hour format)
Flow_Method	Text	Type of flow meter used (option: flume, v-notch weir, volumetric, visual estimate)
Accuracy_Estimate	Text	Observer determination of the quality of their estimate (picklist options: excellent, good, fair, poor, blank)
Visual_Estimate	Text	Value of visual estimate - only used when Flow_Method is "visual estimate"
File_Name	Text	File name data for the uploaded flow meter - only used when Flow_Meter_Make is indicated
Flow_Meter_Make	Text	Make, model and serial number for the flow meter used
Pygmy_Minutes	Text	Pygmy meter spin test time (minutes field) - only set when a Flow_Meter_Make is set to a Pygmy flow meter model
Pygmy_Seconds	Text	Pygmy meter spin test time (seconds field) - only set when a Flow_Meter_Make is set to a Pygmy flow meter model
Flow_Tracker_QC	Yes/No	Flow tracker passes automatic QC test - only set when a Flow_Meter_Make is set to a FlowTracker meter model
Discharge_Loc	Text	Textural description of the discharge measurement location - described as the distance upstream from the gauge
Control_loc	Text	Control location, description, and condition
Comments	Text	Comments on discharge measurement
Flow_Meter_Local	Text	Time zone the flow meter is set to when set to local time (picklist options: blank, MDT for Mountain Daylight-Savings Time, MST for Mountain Standard Time)
DischargeMeters	Floating-point	Amount of discharge in cubic meters per second
DischargeFeet	Floating-point	Amount of discharge in cubic feet per second
Percent_Flow_Captured	Integer	Estimate of the total percent of flow captured by measurement

3.1.7 Table: tbl_Discharge_Readings

Stores each individual discharge reading across a stream. Points are numbered (1,2,3 ... 30) and include the left edge of water (LEW) and right edge of water (REW) sides of the stream. This table is only populated when a Marsh McBirney Flo-mate is used to measure stream discharge. This table connects to an Event via the Discharge Table (tbl_Discharge) in a one-to-many relationship.

3.1.7. tbl_Discharge_Readings

Field name	Field type	Field description
Discharge_Reading_ID	Replication ID	Primary key
Flow_ID	Replication ID	Foreign key - links to the Discharge Table (tbl_Discharge)
Point	Text	Point number measurement was taken at (picklist options: LEW, REW or 1-30)
Method	Text	Method used - discharge is measured at 0.2m and 0.8m when stream is deep enough, or at 0.6m when shallow (picklist options: 0.2/0.8 or 0.6)
LocationMeters	Floating-point	Location of measurement in meters
DepthMeters	Floating-point	Depth of measurement in meters
Velocity1Meters	Floating-point	Velocity in meters per second for 0.2 (where water is >1.5 feet deep and the 0.2/0.8 method is specified) or 0.6 (where water is <1.5 feet deep and the 0.6 method is specified)
Velocity2Meters	Floating-point	Velocity in meters per second for 0.8 (where water is >1.5 feet deep and the 0.2/0.8 method is specified, otherwise blank)
RowOrder	Integer	Ordering field used to keep the rows in the right order (internal use only)
LocationFeet	Floating-point	Location of measurement in feet
DepthFeet	Floating-point	Depth of measurement in feet
Velocity1Feet	Floating-point	Velocity in feet per second for 0.2 (where water is >1.5 feet deep and the 0.2/0.8 method is specified) or 0.6 (where water is <1.5 feet deep and the 0.6 method is specified)
Velocity2Feet	Floating-point	Velocity in feet per second for 0.8 (where water is >1.5 feet deep and the 0.2/0.8 method is specified, otherwise blank)

3.1.8 Table: tbl_Events

Stores Event level information. There is one Event record for each water quality field trip. This is the primary starting table in the water quality database back-end. All data must be connect to an Event. No data have meaning without being tied to a event, so the relationships in the entire backend are all described by how they relate to an event.

Table 3.1.8. tbl_Events

Field name	Field type	Field description
Event_ID	Replication ID	Primary key
Location_ID	Replication ID	Foreign key - links to the Reach Table (tbl_Reach)
Protocol_Name	Text	The name or code of the protocol governing the sampling event
Start_Date	Date/Time	Starting date for the event
End_Date	Date/Time	Ending date for the event (typically the same as start date, unless they run overnight)
Start_Time	Date/Time	Starting time for the sampling event (in 24 hour format)
End_Time	Date/Time	Ending time for the sampling event (note: it is possible for this time to cross midnight, as some streams in hot locations are sampled at night) (in 24 hour format)
Notes	Text	Notes or comments on this sampling event field trip
Local_Time_Datum	Text	Time zone the park is in (picklist options: MDT for Mountain Daylight-Savings Time, MST for Mountain Standard Time)

Table 3.1.8. tbl_Events (continued)

Field name	Field type	Field description
Precip_During	Text	Indicates whether precipitation occurred during sampling, and if so, what type (picklist options: none, rain, freezing rain, hail, sleet, snow)
Precip_24H	Text	Indicates whether precipitation occurred during 24 hours prior to sampling (picklist options: yes or no)
Photo_Observer	Text	Name of the person responsible for taking photographs
Photos_Taken	Yes/No	Indicates whether photos have been taken and can be found in the photographic (ThumbsPlus) database
Observer_List	Text	List of initials of all people present
Lab_Import_Check	Text	Unique number used to cross-reference NWQL lab results with events - generated by concatenating USGS ID, sample date and sample time

3.1.9 Table: tbl_Flood

Stores information about recent flood events. This table connects to an event via the Channel Flow Table (tbl_Channel_Flow) in a one-to-many relationship.

Table 3.1.9. tbl_Flood

Field name	Field type	Field description
Flood_ID	Replication ID	Primary key
Hydro_ID	Replication ID	Foreign key - links to the Channel Flow Table (tbl_Channel_Flow)
Flood_Evid	Text	Flood evidence (picklist options: Fresh debris line above active channel; Fresh debris line in channel; Grasses/shrubs laid over; Other (note in comments); Recent deposition of sediments on floodplain; Recent flood event greater than baseflow but less than bankfull; Riparian vegetation scoured away; None)

3.1.10 Table: tbl_Gauge_Station

Stores the information read from the stream gauge. This table connects to an Event via the Discharge Table (tbl_Discharge) in a one-to-many relationship.

Table 3.1.10. tbl_Gauge_Station

Field name	Field type	Field description
Gauge_Station_ID	Replication ID	Primary key
Flow_ID	Replication ID	Foreign key - links to the Discharge Table (tbl_Discharge)
Read_Time	Date/Time	Time gauge was read (in 12 hour format)
Stage_Ht	Floating-point	Stage height in feet

3.1.11 Table: tbl_Hydro_Substrate

Stores information about the hydrologic substrate of the stream. This table connects to an Event via the Channel Flow Table (tbl_Channel_Flow) in a one-to-many relationship.

Table 3.1.11. tbl_Hydro_Substrate

Field name	Field type	Field description
Hydro_Substrate_ID	Replication ID	Primary key
Hydro_ID	Replication ID	Foreign key - links to the Channel Flow Table (tbl_Channel_Flow)
Substrate	Text	Observed substrates (picklist options: bedrock, boulder, clay, cobble, gravel, other, sand, silt, vegetation, wood)
Dominant	Yes/No	Indicates if this is the dominant substrate

3.1.12 Table: tbl_NWQL_Data

Stores lab results returned from the National Water Quality Lab (NWQL). It is intended to be a transitional table between the NWQL format the NPStoret format, so upon import, some fields are reformatted to be NPStoret compatible. This table connects to an Event by linking directly to the Event Table (tbl_Events) in a one-to-many relationship.

Table 3.1.12. tbl_NWQL_Data

Field name	Field type	Field description
Event_ID	Replication ID	Foreign key - links to the Event Table (tbl_Events)
Activity ID	Text	NPStoret field used to identify the activity ("Lab ID" from NWQL lab results file)
Station ID	Text	Uniquely station identifier – "Site_Name" field in tlu_USGS_SiteName and cross-referenced by USGS ID number ("USGS_Number" in tlu_USGS_SiteName and "USGS Site No" in this table)
USGS Site No	Text	NPStoret field used to store the unique USGS ID for the station ("Station ID" in NWQL lab results file and)
Start Date	Text	Sample start date (format: yyyyymmdd)
Start Time	Text	Sample start time in 24 hour format (format: hhmm)
Start Time Zone	Text	Time zone in which the sample was taken
Sample Medium Code	Text	Medium the sample was drawn from (e.g.: WS = surface water, WG = ground water, WSQ = surface water quality control)
Sample Type	Text	Sample type (e.g.: 9 = Regular, 5 = Duplicate, 2 = Blank)
LocCharNameCode	Text	NPStoret field used to identify local characteristic ("Parameter Code" from NWQL lab results file)
Analytical Procedure ID	Text	"Method" field from lab results – indicates the analytical procedure used by the lab ("Lab ID" from NWQL lab results file)
Dilution factor	Text	Dilution factor used (range: 1-50)
Dilution	Text	Indicates whether sample was diluted (options: yes or no)
Value Type	Text	Indicates whether the value is actual, calculated or estimated
qualifier	Text	Value defined by NWQL that defines particularities of the results
result	Text	Numeric lab result
Result Text	Text	Text of lab result value that has been modified for uploading to NPStoret. SCPN further modifies this field for upload to NPStoret by changing "<" characters to "^".
Result Units	Text	Units the results are reported in.
Remark Code	Text	Three letter lab code that indicates exceptions to the reported results which could effect it's use for data analysis (most typically seen are EHT = "Sample or extract held beyond acceptable holding time", and SUS = "Result value is defined as suspect by data owner")

Result Comment	Text	Comment field structured to satisfy NPStoret – a concatenation of lab reported “result”, “qualifier” and “dilution factor” fields with text headers added and line-feed characters inserted between
RL Type	Text	Reporting level type (mdl = method detection limits,
RL	Text	Reporting level
MDL	Text	Minimum detection level
Parameter	Text	Parameter the rest of the record pertains to (e.g.: nitrite, chloride, specific conductance, etc.) with quotes added to satisfy NPStoret
Lab Code	Text	Lab code for the parameter reported on.
Login Date	Text	Date the lab logged in the results received
Analysis Date	Text	Date the lab performed the analysis
LabID	Text	Name of the lab that did the analysis

3.1.13 Table: tbl_Reach

Stores information about the sampling reach. A reach is the area along a stream where the sampling took place. Each Event in the Event Table (tbl_Events) links to a location in this table in a one-to-many relationship (each Event occurs in one location/reach but each reach can have many Events). Each record in the Reach Table links back to one record in the Stream Table (tbl_Stream) in a many-to-one relationship.

Table 3.1.13. tbl_Reach

Field name	Field type	Field description
Location_ID	Replication ID	Primary Key
Site_ID	Replication ID	Foreign key - links to the Stream Table (tbl_Stream)
USGS_Site_Number	Text	Unique USGS ID for the station
Unit_Code	Text	Unique alpha code for the National Park unit in which the sample site is located
Loc_Name	Text	Unique (SCPN defined) location name – formatted as XXXX_YYY## where: XXXX = park alpha code, YYY = unique 3 letter site name and ## = unique number (when multiple sites)
Station_ID	Text	Unique (SCPN defined) station identification – formatted as XXXX_YYY## where: XXXX = park alpha code, YYY = unique 3 letter site name and ## = unique number (when multiple sites)
Loc_Notes	Text	Notes pertaining to the specific location
Access_Notes	Text	Notes describing access to the site intended to help a future sampler find the same reach
Desc_Name	Text	Descriptive name of the reach which provides additional information to aid in relocating the reach

3.1.14 Table: tbl_Stream

Stores information about the stream each sampling reach is located on. Each Event connects to a Stream via the Reach Table (tbl_Reach) in a many-to-one relationship.

Table 3.1.14. tbl_Stream

Field name	Field type	Field description
Site_ID	Replication ID	Primary key
Site_Name	Text	Name of the stream sampling occurs on
Unit_Code	Text	Unique alpha code for the National Park unit in which the sample site is located

3.1.15 Table: tbl_Temp

Stores water and air temperature data collected in the field, along with information about the instruments used to collect those data. This table connects to an Event by linking directly to the Event Table (tbl_Events) in a one-to-many relationship. The data are collected by the instrument that is currently in the field. When a temperature measuring instrument is first installed, or if an instrument needs to be replaced, this change (or new installment) is also recorded in this table.

Table 3.1.15 Table: tbl_Temp

Field name	Field type	Field description
Temp_ID	Replication ID	Primary key
Event_ID	Replication ID	Foreign key - links to the Event Table (tbl_Events)
Model_Aq_Cur	Text	Manufacturer and model of current water temperature logger
Serial_Num_Aq_Cur	Text	Serial number of current water temperature logger
Download_Time_Aq_Cur	Date/Time	Local download or removal time of current water temperature logger data (in local 12 hour format)
Model_Aq_New	Text	Manufacturer and model of new or replacement water temperature logger
Serial_Num_Aq_New	Text	Serial number of new or replacement water temperature logger
Download_Time_Aq_New	Date/Time	Local deployment time of new or replacement water temperature logger (in 12 hour format)
File_Name_Aq	Text	Water temperature data download file name
Notes_Aq	Text	Notes on sensor condition and actions taken
Model_Air_Cur	Text	Manufacturer and model of current air temperature logger
Serial_Num_Air_Cur	Text	Serial number of current air temperature logger
Download_Time_Air_Cur	Date/Time	Local deployment time of current air temperature logger data (in 12 hour format)
Model_Air_New	Text	Manufacturer and model of new or replacement air temperature logger
Serial_Num_Air_New	Text	Serial number of new or replacement air temperature logger
Download_Time_Air_New	Date/Time	Local deployment time of new or replacement air temperature logger (in 12 hour format)
File_Name_Air	Text	Air temperature data download file name
Notes_Air	Text	Notes on sensor condition and actions taken
NIST_Mod_Ser	Text	NIST traceable thermometer model and serial number
NIST_Temp_Air	Floating-point	NIST traceable thermometer air temperature at time of download in degrees Celsius
NIST_Temp_Aq	Floating-point	NIST traceable thermometer water temperature at time of download in degrees Celsius

3.1.16 Table: tbl_Turb_Readings

Stores turbidimeter data. This table connects to an Event via the Turbidity Table (tbl_Turbidity) in a one-to-many relationship.

Table 3.1.16. tbl_Turb_Readings

Field name	Field type	Field description
Turbidity_Reading_ID	Replication ID	Primary key
Turbidity_ID	Replication ID	Foreign key - links to the Turbidity Table (tbl_Turbidity)
Sample	Integer	Sample number – three to nine readings are made on each turbidity sample, depending upon reliability of the reading
Reading	Floating-point	Turbidity reading in nephelometric turbidity units (NTU)

3.1.17 Table: tbl_Turbidity

Stores information about the turbidimeter and the sampling Event. This table connects to an Event by linking directly to the Event Table (tbl_Events) in a one-to-many relationship.

Table 3.1.17. tbl_Turbidity

Field name	Field type	Field description
Turbidity_ID	Replication ID	Primary key
Event_ID	Replication ID	Foreign key - links to the Event Table (tbl_Events)
Turb_Cal_ID	Replication ID	Foreign key - links to the Turbidity Calibration Table (tbl_Turbidity_Cal)
Model_SN	Text	Make, model and serial number of the turbidimeter
Turb_Read_Median	Floating-point	Calculated median of turbidity readings from all readings as recorded in the Turbidity Readings Table (tbl_Turb_Readings)
Observer	Text	Name of the person who performed the turbidity measurement
Comments	Text	Notes or comments on turbidity measurements

3.1.18 Table: tbl_Turbidity_Cal

Stores turbidimeter calibration information. This table connects to an Event via the Turbidity Table (tbl_Turbidity) in a one-to-many relationship.

Table 3.1.18. tbl_Turbidity_Cal

Field name	Field type	Field description
Turb_Cal_ID	Replication ID	Primary key
Date_Cal	Date/Time	Date the instrument was last calibrated
Date_Cal_Check	Date/Time	Date of current calibration check
Time_Cal_Check	Date/Time	Time of current calibration check (in 12 hour format)
Assigned_Val1	Floating-point	Assigned value 1 (range: 4.00 – 6.00)
Reading1	Floating-point	Read value 1 (range: 4.00 to 6.00)
Assigned_Val2	Floating-point	Assigned value 2 (range: 45.00 to 55.00)
Reading2	Floating-point	Read value 2 (range: 45.00 to 55.00)
Assigned_Val3	Floating-point	Assigned value 3 (range: 400.00 to 600.00)
Reading3	Floating-point	Read value 3 (range: 400.00 to 600.00)

3.1.19 Table: tbl_VersionControl

Stores information about changes made to the database after data were entered. The information in this pertains to the back-end as a whole, and is not connected to any particular Event or location.

Table 3.1.19. tbl_VersionControl

Field name	Field type	Field description
ID	Integer	Auto unique ID
FirstName	Text	First name of the person making the changes
LastName	Text	Last name of the person making the changes
Email	Text	Email address of person making the changes
ChangesDate	Date/Time	Date and time changes were made
ChangeDescription	Text	Short description of changes made and why

3.1.20 Table: tbl_WQ

Stores the basic water quality (core parameter) data, as well as information about the equipment used to measure those data. This table connects to an Event by linking directly to the Event Table (tbl_Events) in a one-to-many relationship. Note: when hydrolab data is uploaded from an Excel file into tbl_WQ_Data, the seven core parameter values (dissolved oxygen, pH, temperature, etc.) that start at, or right after, the Sample_Time are selected for calculating the median values.

Table 3.1.20. tbl_WQ

Field name	Field type	Field description
WQ_ID	Replication ID	Primary key
Event_ID	Replication ID	Foreign key - links to the Event Table (tbl_Events)
WQ_Cal_ID	Replication ID	Foreign key - links to the Water Quality Calibration Table (tbl_WQ_Calibration)
Log_Date_Start	Date/Time	Start date for sonde deployment (used only when a sonde is used)
Log_Time_Start	Date/Time	Start time for sonde deployment (used only when a sonde is used) (in 12 hour format)
Log_Battery_Start	Integer	Percent of battery life left at the start of sonde deployment (used only when a sonde is used) (range: 0 to 100)
Log_Samp_Int	Floating-point	Log file sampling interval (used only when a sonde is used)
Log_Date_End	Date/Time	End date for sonde deployment (used only when a sonde is used)
Log_Time_End	Date/Time	End time for sonde deployment (used only when a sonde is used) (in 12 hour format)
Log_Battery_End	Integer	Percent of battery life left at the end of sonde deployment (used only when a sonde is used)
Log_File_Path	Text	Path and file name of uploaded sonde data file
Comments	Text	Comments on water quality data collection
DO_BP	Floating-point	Dissolved oxygen field calibration value – barometric pressure (range: 400.00 to 800.00)
DO_PreCal_Read_100	Floating-point	Dissolved oxygen field calibration value – pre-calibration meter reading (range: 0.00 to 200.00)

Table 3.1.20. tbl_WQ (continued)

Field name	Field type	Field description
DO_PostCal_Read_100	Floating-point	Dissolved oxygen field calibration value – post-calibration meter reading (range: 0.00 to 200.00)
DO_PreCal_Temp_100	Floating-point	Dissolved oxygen field calibration value – pre-calibration temperature (range: -5.00 to 45.00)
DO_PostCal_Temp_100	Floating-point	Dissolved oxygen field calibration value – post-calibration temperature (range: -5.00 to 45.00)
Hydrolab_File	Text	Path and file name of uploaded hydrolab data file
Sample_Time	Date/Time	Sample time (note: among other things, this value is used for picking 7 rows from imported hydrolab data)
Cal_Comments	Text	Comments and notes on equipment calibration
No_Calibration	Yes/No	Indicates hydrolab was not calibrated in the field
Med_pH	Floating-point	Median of the seven selected pH values from tbl_WQ_Data (range: 0.00 to 14.00)
Med_DOVol	Floating-point	Median of the seven selected dissolved oxygen per volume values from tbl_WQ_Data (range: 0.00 to 20.00)
Med_H2OTemp	Floating-point	Median of the seven selected water temp values from tbl_WQ_Data (range: -5.00 to 45.00)
Med_DOSat	Floating-point	Median of the seven selected saturated dissolved oxygen values from tbl_WQ_Data (range: 0.00 to 200.00)
Med_SpCond	Floating-point	Median of the seven selected specific conductance values from tbl_WQ_Data (range: 0.00 to 5000.00)

3.1.21 Table: tbl_WQ_Calibration

Stores field calibration information for the hydrolab multi-parameter sonde. This table connects to an Event via the Water Quality Core Parameter Table (tbl_WQ) in a one-to-many relationship.

3.1.21 Table: tbl_WQ_Calibration

Field name	Field type	Field description
WQ_Cal_ID	Replication ID	Primary key
Cal_Date	Date/Time	Calibration date
Cal_Time	Date/Time	Calibration time (12 hour format)
Make_Model	Text	Make and model of the water quality instrument
SCPN_Name	Text	SCPN defined name for the water quality instrument
Inst_Time	Text	Indicates whether instrument is set to local time (options: Yes, No or Unk)
Cal_Location	Text	Indicates where calibration occurred (Note: a single calibration may be used across several sampling events)
FieldCalib_Observer	Text	Name of the person who performed the field calibration
Temp_Water	Floating-point	Stream water temperature (in degrees Celsius) at the time of calibration (range: -5.00 to 45.00)
pH_Lot_No_7	Text	Lot number for the pH 7 solution used
pH_PreCal_Temp_7	Floating-point	Pre-calibration temperature for pH 7 (range: -5.00 to 45.00)
pH_PreCal_Read_7	Floating-point	Pre-calibration reading for pH 7 (range: 0 to 14.00)
PH_PostCal_Temp_7	Floating-point	Post-calibration temperature for pH 7 (range: -5.00 to 45.00)
pH_PostCal_Read_7	Floating-point	Post-calibration reading for pH 7 (range: 0 to 14.00)

3.1.21 Table: tbl_WQ_Calibration (continued)

Field name	Field type	Field description
pH_Lot_No_10	Text	Lot number for the pH 10 solution used
pH_PreCal_Temp_10	Floating-point	Pre-calibration temperature for pH 10 (range: -5.00 to 45.00)
pH_PreCal_Read_10	Floating-point	Post-calibration temperature for pH 10 (range: -5.00 to 45.00)
pH_PostCal_Read_10	Floating-point	Pre-calibration reading for pH 10 (range: 0 to 14.00)
PH_PostCal_Temp_10	Floating-point	Post-calibration reading for pH 10 (range: 0 to 14.00)
sc_Lot_No_100	Text	Lot number for the 100 µs/cm conductance solution used
sc_PreCal_Temp_100	Floating-point	Pre-calibration temperature for 100 µs/cm conductance solution (range: -5.00 to 45.00)
sc_PreCal_Read_100	Floating-point	Pre-calibration reading for 100 µs/cm conductance solution (range: 0 to 200.00)
sc_PostCal_Temp_100	Floating-point	Post-calibration temperature for 100 µs/cm conductance solution (range: -5.00 to 45.00)
sc_PostCal_Read_100	Floating-point	Post-calibration reading for 100 µs/cm conductance solution (range: 0 to 200.00)
sc_Lot_No_1413	Text	Lot number for the 1413 µs/cm conductance solution used
sc_PreCal_Temp_1413	Floating-point	Pre-calibration temperature for 1413 µs/cm conductance solution (range: -5.00 to 45.00)
sc_PreCal_Read_1413	Floating-point	Pre-calibration reading for 1413 µs/cm conductance solution (range: 0 to 2000.00)
sc_PostCal_Temp_1413	Floating-point	Post-calibration temperature for 1413 µs/cm conductance solution (range: -5.00 to 45.00)
sc_PostCal_Read_1413	Floating-point	Post-calibration reading for 1413 µs/cm conductance solution (range: 0 to 2000.00)
sc_Lot_No_Other	Text	Lot number for the additional conductance solution (if used)
sc_Value_Other	Single	Conductance value of additional solution (if used)
sc_PreCal_Temp_Other	Floating-point	Pre-calibration temperature for additional conductance solution (if used)
sc_PreCal_Read_Other	Floating-point	Pre-calibration reading for additional conductance solution (if used)
sc_PostCal_Temp_Other	Floating-point	Post-calibration temperature for additional conductance solution (if used)
sc_PostCal_Read_Other	Floating-point	Post-calibration reading for additional conductance solution (if used)
ph_lower	Floating-point	Lower pH value calibrated
ph_higher	Floating-point	Higher pH value calibrated

3.1.22 Table: tbl_WQ_Data

Stores data uploaded from the hydrolab multi-parameter sonde. This table connects to an Event by linking directly to the Event Table (tbl_Events) in a one-to-many relationship.

Table 3.1.22. tbl_WQ_Data

Field name	Field type	Field description
WQ_Data_ID	Replication ID	Primary key
Event_ID	Replication ID	Foreign key - links to the Event Table (tbl_Events)
Sample_Date	Date/Time	Date the sample was taken
Sample_Time	Date/Time	Time the sample was taken (in 12 hour format)
IBatt	Integer	Percent battery remaining (range: 0 to 100)
Temp	Floating-point	Water temperature (range: -5.00 to 45.00)
SpCond	Integer	Water specific conductanceivity (range: 0 to 5000)
pH	Floating-point	Water pH value (range: 0 to 14.00)
LDO%	Floating-point	Percent saturation luminescent dissolved oxygen (range: 0 to 200.00)
LDO	Floating-point	Water luminescent dissolved oxygen (range: 0 to 20.00)
BP	Integer	Barometric pressure
Selected	Yes/No	Indicates whether this value is one of the 7 selected from which the median value is calculated and entered into tbl_WQ – selected values are either the 7 values that most closely follow the Sample_Time field value (in tbl_WQ) or those which have been manually selected
Manually_Entered	Yes/No	Indicates value was manually selected to be one of the 7 from which the median value is calculated (see also description for “Selected” field in this table)
ReadInOrder	Integer	Order in which values were uploaded

3.1.23 Table: tlu_Contacts

Stores the contact information for the people collecting water quality data.

Table 3.1.23. tlu_Contacts

Field name	Field type	Field description
Contact_ID	Replication ID	Primary key
Last_Name	Text	Last name
First_Name	Text	First name
Middle_Init	Text	Middle initial
Organization	Text	Organization or employer
Position_Title	Text	Title or position description
Address_Type	Text	Indicates type of address entered (mailing, physical or both)
Address	Text	Street address
Address2	Text	Address line 2, suite, apartment number
City	Text	City or town
State_Code	Text	State or province
Zip_Code	Text	Postal zip code
Country	Text	Country
Email_Address	Text	E-mail address
Work_Phone	Text	Phone number
Work_Extension	Text	Phone extension
Contact_Notes	Text	Contact notes

3.1.24 Table: tlu_Def_DaylightTime

Stores the start and end dates for daylight saving time changes by year.

Table 3.1.24. tlu_Def_DaylightTime

Field name	Field type	Field description
VisitYear	Text	Year of sampling event
StartDate	Date/Time	Start date (in the fall – the day clocks are set ahead one hour)
EndDate	Date/Time	End date (in the spring – the day clocks are set back one hour)

3.1.25 Table: tlu_Enumerations

Stores various enumerations that may be used in this database. An enumeration is a complete, ordered listing of all the items in a collection.

Table 3.1.25. tlu_Enumerations

Field name	Field type	Field description
Enum_Code	Text	Enumeration value – used as the lookup value
Enum_Description	Text	Description of the enumeration
Enum_Group	Text	Category group the enumeration belongs to
Sort_Order	Integer	Order in which to sort lookup values

3.1.26 Table: tlu_EPA_STORET_Lab_Remarks

Stores the descriptions for remarks that may be included in lab results returned from the EPA lab and stored into NPStoret.

Table 3.1.26. tlu_EPA_STORET_Lab_Remarks

Field name	Field type	Field description
TSRLBRMK_IS_NUMBER	Integer	Unique identifier
TSRLBRMK_ORG_ID	Text	Organization code
SHORT_NAME	Text	Remark code
DESCRIPTION_TEXT	Text	Remark description
D_USERID_CODE	Text	User identifier
D_LAST_UPDATE_TS	Date/Time	Date last updated

3.1.27 Table: tlu_Flood

Stores the list of flood evidence descriptions allowed.

Table 3.1.27. tlu_Flood

Field name	Field type	Field description
Flood_Evidence	Text	Description of flood evidence

3.1.28 Table: tlu_Observers

Stores the list of people involved with making or observing the various field measurements.

Table 3.1.28. tlu_Observers

Field name	Field type	Field description
Observer_Name	Text	Name of person, or persons, involved in field measurement

3.1.29 Table: tlu_Park_Zones

This table indicates which parks observe daylight savings time.

Table 3.1.29. tlu_Park_Zones

Field name	Field type	Field description
ParkCode	Text	Unique alpha code for the National Park unit in which the sample site is located
blnDSObserved	Yes/No	Indicates whether park unit observes daylight savings time or not (0 = no, -1 = yes)
Zone	Text	Time zone the park unit is located within (M = Mountain)
Comment	Text	Notes or comments

3.1.30 Table: tlu_USGS_SiteName

This table is used to fill in the Station ID field in tbl_NWQL_Data table for importation to NPStoret.

Table 3.1.30. tlu_USGS_SiteName

Field name	Field type	Field description
USGS_Number	Text	Unique USGS ID for the station
Site_Name	Text	Unique (SCPN defined) sample site name – format as XXXX_YYY## where: XXXX = park alpha code, YYY = unique 3 letter site name and ## = unique number (when multiple sites)
Park_Name	Text	Unique alpha code for the National Park unit in which the sample site is located

3.1.31 Table: tlu_Val_Qual_Cd_to_Remark

This table provides additional information on the remark codes returned with the lab results from the USGS National Water Quality Lab.

Table 3.1.31. tlu_Val_Qual_Cd_to_Remark

Field name	Field type	Field description
ID	Integer	Primary key
Remark	Text	Remark code
val_qual_cd	Text	Remark symbol
val_qual_nm	Text	Descriptive text

3.2 Secondary (shipping) back-end database tables

This section describes the tables contained within the secondary back-end database. This database contains shipping information used to track water samples that are sent to the USGS National Water Quality Lab (NWQL). Figure D-2 shows the relationships between the tables of the secondary (shipping) back-end.

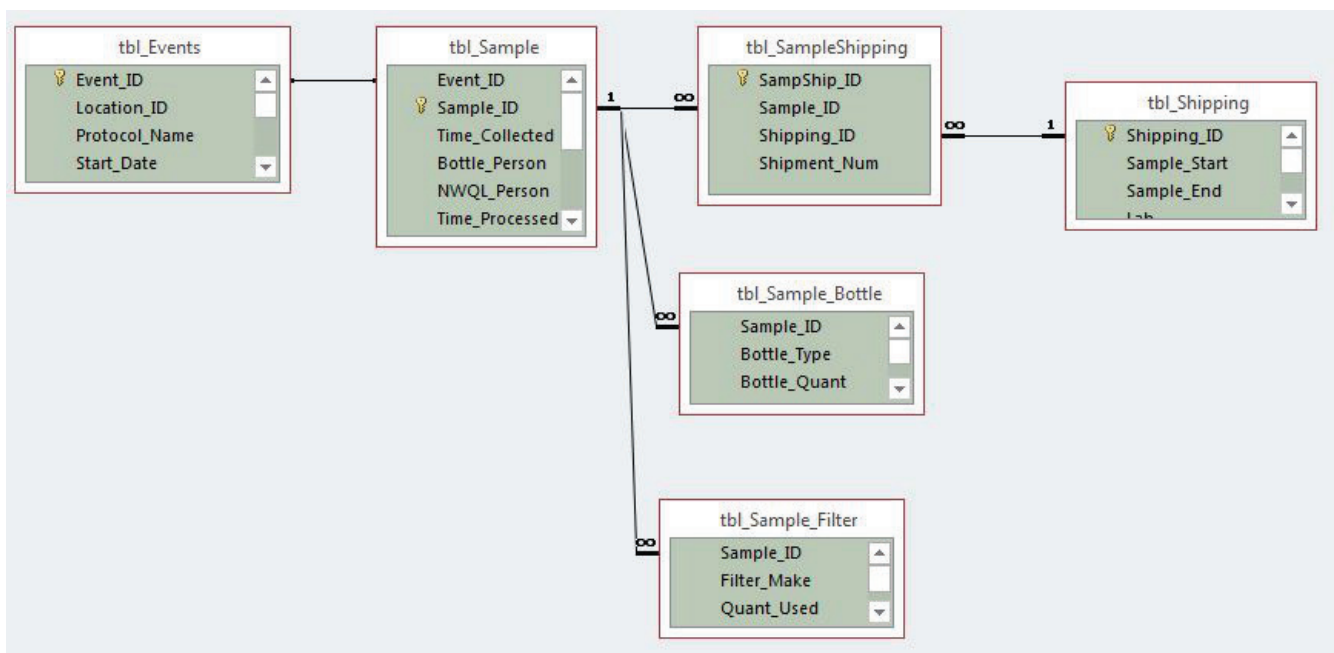


Figure D-2. Data model for the secondary (shipping) back-end for the SCPN Water Quality monitoring program.

3.2.1 Table: tbl_Sample

Stores information about each sample that is shipped to a water quality testing laboratory. This table connects to an Event by linking directly to the Event Table (tbl_Events) in the primary back end, in a one-to-one relationship. This is the main table for all data stored in the secondary (shipping) Water Quality back-end.

Table 3.2.1. tbl_Sample

Field name	Field type	Field description
Sample_ID	Replication ID	Primary key
Event_ID	Replication ID	Foreign key - links to the Event Table (tbl_Events)
Time_Collected	Date/Time	Time sample was collected (12 hour format)
Bottle_Person	Text	Name of the person who collected all the bottled samples
NWQL_Person	Text	Name of the person shipping the collected samples to the lab
Time_Processed	Date/Time	Time the sample was processed (12 hour format)
Samples_chilled	Text	Indicates whether the sample was chilled or not (options: yes, no)
Filt_Location	Text	The location where the filtration occurred (options: on-site, at car, indoors, or chamber)
Pump_Serial_No	Text	Make and serial number of the pump used
Schedule_No	Text	Schedule number/name
Treat_Code	Text	Treatment code
Comments	Text	Notes or comments

3.2.2 Table: tbl_Sample_Bottle

Stores information about each bottle that is shipped to the NWQL for analysis. This table connects to an Event via the Sample (tbl_Sample) in a one-to-many relationship.

Table 3.2.2. tbl_Sample_Bottle

Field name	Field type	Field description
Sample_ID	Replication ID	Foreign key - links to the Sample Table (tbl_Sample)
Bottle_Type	Text	Type of bottle shipped
Bottle_Quant	Integer	Number of bottles shipped
Lot_Num	Text	The lot number the bottle comes from
Treatment	Text	Treatment code
Schedule	Text	Schedule number
Shipment_Num	Integer	Shipment number the bottle was sent in

3.2.3 Table: tbl_Sample_Filter

Stores information about the filter used to process water to be shipped to the NWQL. This table connects to an event via the Sample (tbl_Sample) in a one-to-many relationship.

Table 3.2.3. tbl_Sample_Filter

Field name	Field type	Field description
Sample_ID	Replication ID	Foreign key - links to the Sample Table (tbl_Sample)
Filter_Make	Text	Manufacturer and model of the filter used
Quant_Used	Integer	Quantity used
Lot_Num	Text	Filter lot number

3.2.4 Table: tbl_SampleShipping

This is the cross reference table between shipping and samples shipped. Each even can have multiple samples that are shipped in multiple shipments. This table is used to track that many-to-many relationship

Table 3.2.4. tbl_SampleShipping

Field name	Field type	Field description
SampShip_ID	Replication ID	Primary key
Sample_ID	Replication ID	Foreign key - links to the Sample Table (tbl_Sample)
Shipping_ID	Replication ID	Foreign key - links to the Shipping Table (tbl_Shipping)
Shipment_Num	Integer	The shipment number each bottle was shipped in

3.2.5 Table: tbl_Shipping

Stores shipping information for samples sent to the NWQL for analysis.

Table 3.2.5. tbl_Shipping

Field name	Field type	Field description
Shipping_ID	Replication ID	Primary key
Sample_Start	Date/Time	Start date for samples being sent
Sample_End	Date/Time	End date for samples being sent
Lab	Text	Name of lab samples were sent to
Tracking_Number	Text	Shipping tracking number
Containers_Number	Integer	Number of containers shipped
Containers_Type	Text	Type of containers shipped
Method	Text	Method of shipment
Location	Text	Location from which the shipment was made
Date_Shipped	Date/Time	Date the package was dropped off to be shipped
Date_Received	Date/Time	Date the package was received by lab
Who_Shipped	Text	Name of the person who shipped the samples
Notes_Shipping	Text	Notes on shipping, data abnormalities, etc.
Notes_Sampling	Text	Notes on sampling
Shipper	Text	The name of the company used to do the shipping (options: FedEx, UPS, USPS)
Time_Shipped	Date/Time	Time package was dropped off to be shipped (24 hour format)

Appendix E

Sample Data Summary Report on Water Quality Monitoring for Stream and Springs in Southern Colorado Plateau Network Parks

Data summary reports for water quality monitoring are available from the Southern Colorado Plateau Network website (<http://science.nature.nps.gov/im/units/scpn/publications.cfm?tab=2>), and from the NPS IRMA Portal (<https://irma.nps.gov/App/Portal/Home>).

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science



Water Quality Monitoring for the Mancos River in Mesa Verde National Park

2011 Summary Report

Natural Resource Data Series NPS/SCPN/NRDS—2013/567





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ON THE COVER
Manco River, Mesa Verde NP
Photograph by SCPN

Water Quality Monitoring for the Mancos River in Mesa Verde National Park

2011 Summary Report

Natural Resource Data Series NPS/SCPN/NRDS—2013/567

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

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

The Natural Resource Data Series is intended for the timely release of basic data sets and data summaries. Care has been taken to assure accuracy of raw data values, but a thorough analysis and interpretation of the data has not been completed. Consequently, the initial analyses of data in this report are provisional and subject to change. Please direct any data requests to the SCPN Data Manager.

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.

Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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

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This report is available from the Southern Colorado Plateau Network (<http://science.nature.nps.gov/im/units/scpn/>), and the Natural Resource Publications Management Web site (<http://www.nature.nps.gov/publications/nrpm/>) on the Internet. To receive this report in a format optimized for screen readers, please email irma@nps.gov.

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1 Introduction

The National Park Service Inventory and Monitoring Program was designed to determine the current status and monitor long-term trends in the condition of park natural resources, providing park managers with a scientific foundation for making decisions and working with other agencies and the public to protect park ecosystems. Hydrologic vital signs are the fundamental components defining overall riparian and aquatic ecosystem integrity. The Southern Colorado Plateau Network (SCPN) has identified 7 vital signs pertaining to riparian and spring ecosystems: 1) stream water quality, 2) aquatic macroinvertebrates, 3) stream flow and depth to groundwater, 4) spring water quality, 5) fluvial geomorphology, 6) riparian vegetation, composition, and structure, and 7) spring ecosystems. These vital signs are closely related and are all included in the Vital Signs Monitoring Plan for the Southern Colorado Plateau Network (Thomas et al. 2006). The context and ecological significance of these vital signs are further explained in Scott et al. (2005). In this report we focus on stream water quality.

Specific objectives of stream water quality monitoring for the SCPN parks are

- Determine status and trends in selected core water quality parameters (water temperature, pH, specific conductivity, dissolved oxygen, turbidity and discharge) at selected sites in priority streams within SCPN parks.
- Determine status and trends of selected water quality constituents, including bacteria, nutrients, major elements, and trace metals at selected sites in priority streams within SCPN parks.
- Compare water quality data against state standards for chronic exceedances. Multiple exceedances in a year typically indicate non-compliance.

1.1 Selecting potential water quality monitoring sites

We targeted SCPN streams and springs with potential for water quality monitoring by reviewing (1) water quality data inventory and analysis reports prepared by the Water Resources Division (WRD) of the National Park Service (NPS), (2) a USGS summary and review of available water quality data from streams in SCPN parks (Brown 2008), (3) data collected during a Level 1 water quality inventory of streams in SCPN parks (Macy and Monroe 2006), and (4) results of water quality planning meetings with park staff.

SCPN water bodies were selected for water quality monitoring based on the following criteria:

- 303(d) listed waters¹ - where previous sampling indicates one or more parameters regularly approach or exceed established water quality standards or recommended levels
- waters with demonstrated threat levels – where an analysis of existing data indicate that measured conditions regularly approach or exceed standards or recommended levels, but where the frequency of exceedances or the quality of the database do not support a 303(d) listing
- pristine waters – where there is no direct impact of human activities (provides baseline data)
- ecological significance – presence of unique species or species of concern
- waters of management concern – where past sampling may not indicate constituent values of concern, but where anthropogenic activities indicate that contamination is a significant threat
- historic data – waters identified as important, for which substantial historic water quality data is available
- data gaps – waters identified as important, but where little or no water quality information exists

Water quality monitoring sites are located whenever possible where a history of water quality data collection exists, and are co-located with SCPN aquatic macroinvertebrate monitoring sites whenever possible. NPS core water quality data and water quality samples are collected at regular intervals throughout the year. Diurnal variation in NPS core water quality parameters are characterized by deploying a multi-parameter sonde to collect

¹ Under section 303(d) of the Clean Water Act, states, territories, and authorized tribes are required to develop lists of impaired waters—waters that are too polluted or otherwise degraded to meet the water quality standards set by states, territories, or authorized tribes (EPA 2011).

data for as many days as possible during base flows. Water quality samples are analyzed by SCPN staff and by a

qualified contract laboratory.

1.2 Water quality monitoring at Mesa Verde National Park

The Mancos River is a perennial stream flowing from Colorado's La Plata Mountains to its confluence with the San Juan River in northwestern New Mexico. Approximately four miles of the river flow along the eastern boundary of Mesa Verde National Park (MEVE). Upstream from the park, Jackson Gulch Dam diverts water from the Mancos River; both the dam and numerous diversions in the Mancos Valley reduce the amount of Mancos River flow that reaches MEVE (Colorado Water Trust 2011). In August of 2000, the NPS, in cooperation with the United States Geological Survey (USGS), installed a streamflow gaging station on the Mancos River within MEVE (Figure 1).

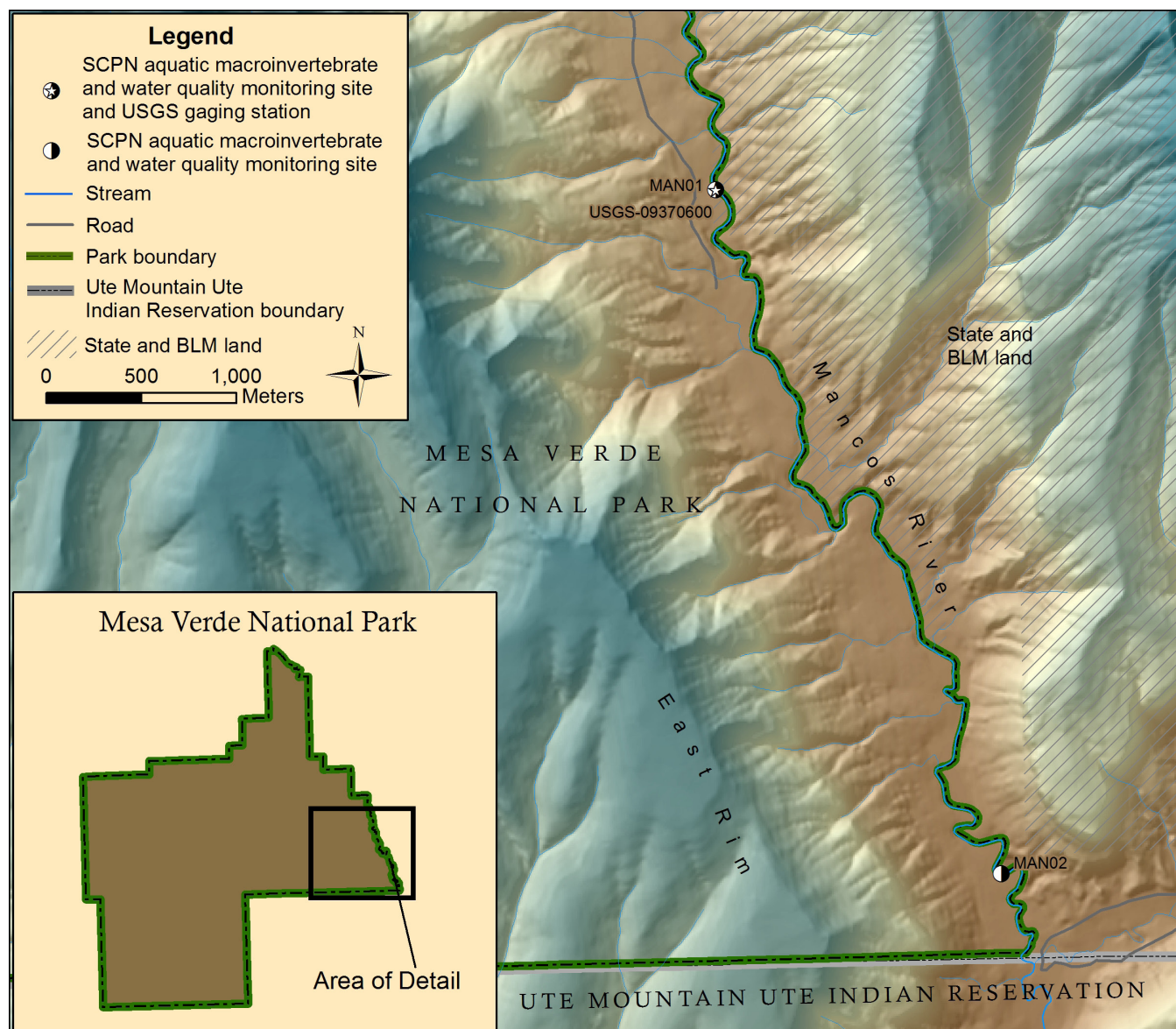


Figure 1. Map of the Mancos River, Mesa Verde NP, Colorado, with the location of Southern Colorado Plateau Network's aquatic macroinvertebrate and water quality monitoring sites MAN01 and MAN02 on the Mancos River, visited in 2011.

Water quality concerns within the park include insecticide, algicide, and herbicide applications (Brown 2008). Adjacent agriculture and sewage-treatment facilities have been sources of nutrient and bacterial contamination

(Thomas et al. 2006). Irrigation practices along the Mancos River and its tributaries are suspected to have contributed to elevated salinity levels (Yochum 2004). Drought and wildfire have also affected the river. In 2000, a high-intensity fire burned portions of the watershed in MEVE; fire retardant drops during the fire resulted in fish kills (San Miguel, G., Natural Resource Manager, Mesa Verde NP, personal communication, 28 July 2011).

Data documenting water quality conditions in the Mancos River are sparse. The most recent samples collected in the park were part of a Level 1 water quality inventory of water bodies in SCPN parks completed by the USGS in 2005 and 2006 (Macy and Monroe 2006). An assessment of the functional condition of the Mancos River conducted in 2006 found high concentrations of algal blooms, probably caused by high solar exposure, combined with a wide shallow channel near MAN01, and a possible indicator of poor water quality (Stacey 2007).

In 2010, SCPN implemented water quality monitoring on the Mancos River in MEVE. SCPN water quality monitoring occurs at two sites on the Mancos River in MEVE:

- *Mancos River at Gage* (MEVEMAN01), identified in this report as MAN01 (appendix A), was established in 2010 as SCPN's primary water quality monitoring site. The site is co-located with a SCPN aquatic macroinvertebrate monitoring site and the USGS streamflow gaging station Mancos River at Anitas Flat below Mancos, CO (USGS 09370600).
- *Mancos River above Downstream Park Boundary* (MEVEMAN02), identified in this report as MAN02, is a SCPN aquatic macroinvertebrate monitoring site. Once per year, NPS core water quality data are collected at this site.

In 2011, SCPN staff made a total of ten water quality sampling visits to MAN01 at regular intervals throughout the year. Limited water quality data were also collected at MAN02, concurrent with the aquatic macroinvertebrate sampling event on September 9. This report documents SCPN water quality monitoring activities at MEVE in 2011 and summarizes the data collected.

2 Methods

A brief description of water quality data collection and processing methodologies followed by SCPN staff at MEVE during 2011 is presented here. Detailed descriptions of these procedures will be available in SCPN's water quality monitoring protocol (Monroe et al. in preparation).

2.1 Water quality core parameters

National Park Service core water quality parameters include water temperature, pH, specific conductivity, dissolved oxygen, turbidity, and discharge. During each site visit, we noted the hydrologic conditions and collected water quality core parameter data using the following methods:

- Water and air temperatures were recorded at 15-minute intervals by a HOBO Pendant Temperature/Alarm Logger #UA-001-64, and a HOBO TidbiT v2 Water Temperature Data Logger, #UTBI-001 (Onset Computer Corporation) deployed at the monitoring site. The sensors were downloaded and maintenance was performed during each site visit. Sensor accuracy was confirmed using a NIST-certified thermometer during each download.
- As soon as possible after arrival at the site a multi-parameter sonde (Hydrolab-MS5; Hach Inc.) was calibrated and deployed in a well-mixed part of the stream channel, logging temperature, pH, specific conductivity, and dissolved oxygen data at 5-second intervals. The sonde was left stationary in the stream for the entire site visit.
- Turbidity samples were kept on ice for a maximum of 24 hours, and analyzed with a HACH 2100P Portable Turbidimeter (Hach Inc.).
- Discharge was measured using a FlowTracker Acoustic Doppler Velocimeter (SonTek Inc.).

We attempted to obtain all measurements and samples as close in time to one another as possible. Streamflow data from the USGS gaging station documented flow variation during site visits and throughout the year at 15-minute intervals.

In addition to the regular site visits, which were generally less than two hours long, we collected temperature, pH, specific conductivity, and dissolved oxygen data at 15-minute intervals from October 7–22 to characterize temporal variability of these parameters

2.2 Water quality samples

During each site visit, we collected a sample for bacterial analysis by dipping a sample bottle at the center of flow. The sample was then analyzed by SCPN staff for total coliforms and *E. coli* using the Quanti-Tray® 2000 system (IDEXX Inc.). We collected samples to be tested for other analytes in a similar manner. Sample water was filtered and/or acid-treated (as required), kept on ice, and shipped to the contract laboratory. For 2011, SCPN contracted with the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado for analysis of water samples for selected water quality constituents. These analyses fall into three categories: nutrients, major elements and trace metals (Table 1). Information documenting NWQL methods are included in the SCPN water quality monitoring protocol (Monroe et al., in preparation).

Also in 2011, SCPN entered into a partnership with EPA to sample for a suite of contaminants of emerging concern (CEC), which include pharmaceuticals, personal care products, waste water indicators, and pesticides, to develop a baseline dataset documenting the occurrence of these contaminants within SCPN parks. Seven sampling events for these occurred at MAN01 between the months of May and October. Samples were kept on ice and analyzed at the EPA Region 8 Laboratory in Golden, Colorado within seven days of collection, as required.

2.3 Data handling and analysis

All SCPN water quality data are entered in NPSTORET, v.1.83, a Microsoft Access database created by the Water Resources Division of the National Park Service. All multiparameter sonde electronic data, discharge, and temperature logger files are stored on the SCPN server.

Table 1. USGS National Water Quality Laboratory and U.S. Environmental Protection Agency Laboratory sample analytes.

Analytical group	Analytes
Nutrients	ammonia, nitrite, nitrite + nitrate, orthophosphate
Major elements	calcium, chloride, fluoride, magnesium, potassium, silica, sodium, sulfate, acid neutralizing capacity (ANC; as CaCO ₃), total dissolved solids
Trace metals	aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, uranium, vanadium, zinc
Contaminants of emerging concern: pharmaceuticals, personal care products, waste water indicators, pesticides	see Appendix B of this report, Table B4

In this report, we only include the median values of a subset of seven consecutive multiparameter sonde measurements, with the exception of the data presented in section 3.3: *Temporal variability of core parameter data from the Mancos River in MEVE*. Similarly, only the median values for each set of turbidity triplicate samples are presented. For total coliforms and *E. coli* samples, most-probable numbers (MPN/100 mL) are reported; these were determined using a lookup table provided by the manufacturer (IDEXX Inc.).

Where applicable, we compared our results against the State of Colorado’s 2012 water quality standards (Colorado Department of Public Health and Environment [CDPHE] 2012a,b) and noted any exceedances of the applicable standards.

2.4 Understanding water quality data and standards

The NPS Natural Resource Challenge (NRC) provides funding for water quality monitoring in NPS park units. This funding supports efforts directed towards attainment of NPS’s long-term goals to protect pristine water quality and improve impaired water quality by supporting Clean Water Act protections and provisions for designated unimpaired and impaired waters. Preliminary analysis of data available through the water quality data synthesis (Brown 2008), a Level 1 water quality inventory (Macy and Monroe 2006), and monitoring indicate that water quality conditions at many SCPN parks exceed established USEPA, State or Tribal standards.

The State of Colorado has developed statewide water quality standards and criteria for surface waters, and specific additional criteria relevant to the reach of the Mancos River within MEVE, to meet requirements of the Federal Clean Water Act (CDPHE 2012a,b). This report includes all water quality standards and criteria applicable to the Mancos River. A water quality standard refers to a specific parameter and its associated beneficial-use designation, in conjunction with a criterion, which is the numeric component against which a result is compared. For example, the standard for chronic selenium (parameter) for aquatic life (beneficial use designation) is 4.6 µg/L (numeric criterion).

The SCPN water quality monitoring program collects samples several times per year at regular intervals in order to document the range of hydrologic conditions that occur, with a focus on base flow conditions. Thus, rare and short-term events are often not captured. Grab samples represent conditions at the point and time of sampling; they do not represent the condition of the entire water body, spatially or temporally.

In this report, results for each parameter are evaluated against applicable water quality standards as defined for each stream by the State of Colorado. Colorado surface waters can have up to five beneficial use classifications. Three appropriate beneficial uses are identified for the reach of the Mancos River and are discussed in this report. These are class 2 warm water aquatic life, agriculture, and recreation (class N from Nov. 1 to April 30, and class E from May 1 to Oct. 31) (CDPHE 2012b). Each beneficial use may have different criteria for one parameter.

SCPN water samples are analyzed for dissolved parameters. This means stream water is passed through a 0.45 µm filter in order to remove the particulate component prior to being shipped for analysis. Water quality criteria may

be expressed in terms of either the dissolved or total fraction of a sample. The total fraction concentration will be greater than the dissolved fraction. Because of this, only criteria for dissolved parameters are applicable to our samples, and only these criteria are listed in the Results sections.

For *E. coli*, we compared our results against the criteria for class N (not primary contact use) and class E (existing primary contact use) recreation, depending upon the time of year the samples were collected. The Colorado water quality criterion is expressed as the number of colony forming units per 100 mL (cfu/100 mL). SCPN bacteria data are expressed as a most probable number (MPN) per 100 mL. MPN is a statistical estimate of the number of bacteria per unit volume of a sample, determined by using a lookup table provided by the manufacturer (IDEXX Inc.). Although the Colorado criterion is expressed as cfu/100 mL and does not assume an estimation, the two units are comparable.

2.4.1 Chronic and acute standards

Numeric criteria for aquatic life water quality standards address potential effects of both chronic exposure to a parameter over an extended period of time (months) and acute exposure over a short period of time (hours or days). Acute criteria are based on either a single sample or an average of samples collected during a one-day period. Criteria are much lower for chronic exposure than for acute exposure and are not necessarily comparable to the results obtained from a one-time grab sample. This is because chronic standards are based on either a single representative sample or the average of all samples collected during a thirty-day period (CDPHE 2012a); the exact number of samples is not specified. When determining attainment of both acute and chronic standards, the representative nature of the data must be considered. From a compliance standpoint, the acute instantaneous criteria afford the only direct comparison for such data because they apply to a single sample. However, from a resource-conservation standpoint, instantaneous grab-sample data, when compared against more stringent chronic criteria, can provide a means of early warning and an indication of a problem that may require more attention. Therefore, we have identified when results are outside the chronic criterion in the Results section of this report.

2.4.2 Regulatory authority

The National Park Service does not have regulatory authority over waters in U.S., or even the authority to make assessments for designated use. This report compares water quality data to designated use criteria without stating whether a designated use was attained. Those designations are reported by the states or tribes in their triennial 305(b) reports to Congress. However, the NPS cooperates with states and tribes in collecting data used in the protection of water bodies under state jurisdiction. Definitions of water quality standards according to the states of Arizona, Colorado, New Mexico, Utah, and the Navajo Nation are provided in the SCPN Streams and Springs Water Quality Monitoring Protocol (Monroe et al. in review).

3 Results

3.1 Water quality core parameter data

Summary statistics for water quality core parameter data collected at MAN01 and MAN02 during 2011 are presented in Table 2 and Table 3; 2010 data for both sites are included for comparison. Complete results for MAN01 are displayed in Appendix B. Measurements at MAN02 were collected on September 9 and were similar to those collected at MAN01 on September 10. At MAN01, the data exhibited considerable within-year variability for several parameters (Table 2), but there were no exceedances of Colorado state water quality standards at MAN01 or MAN02 during our site visits (CDPHE 2012a,b).

Table 2. Summary of water quality core parameter data from samples collected at MAN01 on the Mancos River in Mesa Verde NP in 2010 (n=8) and 2011 (n=10, except for discharge, where n=9). Associated Colorado state aquatic life criterion is indicated for each parameter; “n/c” means that no criterion exists for a specific parameter.

Core parameter	2010		2011		CO state aquatic life criterion
	Median	Range	Median	Range	
Water temperature (°C)	8.5	0.4 – 25.2	7.2	0.0 – 23.4	^a
pH	8.3	7.9 – 8.6	8.3	7.9 – 8.4	>6.5 or <9
Specific conductivity (µS/cm)	1230	345 – 2210	1263	282 – 1350	n/c
Dissolved oxygen (mg/L)	9.3	7.2 – 11.4	9.5	6.8 – 11.4	>5
Turbidity (NTU)	12	7.2 – 120	25	7.9 – 150	n/c
Discharge (cfs)	18	4.6 - 269	20.3	6.3 – 213	n/c

^a See section 3.1 in text

Table 3. Water quality core parameter data collected from MAN02 on the Mancos River in Mesa Verde NP, concurrently with the collection of aquatic macroinvertebrate monitoring on one day in September 2010 and 2011 (n=1 for 2010 and 2011). The associated Colorado state aquatic life criterion is indicated for each parameter; “n/c” indicates that no criterion exists for a specific parameter.

Core parameter	2010	2011	CO state aquatic life criterion
Water temperature (°C)	13.4	14.4	^a
pH	8.3	8.4	>6.5 or <9
Specific conductivity (µS/cm)	1330	1283	n/c
Dissolved oxygen (mg/L)	8.6	8.5	>5
Turbidity (NTU)	18	9.0	n/c
Discharge (cfs)	10.4	10.8	n/c

^a See section 3.1 in text

Water and air temperature data from MAN01 for 2011 are summarized below and shown in Figure 2. The water in the Mancos River was frozen during portions of December, January, and February. The maximum water temperature for the year occurred on July 7 and was 29.2°C. The average water temperature was 9.0°C. The maximum air temperature was 36.9°C and occurred on July 2, while the minimum temperature of -31.0°C occurred on January 2. The average air temperature for the year was 7.7°C.

This section of the Mancos River is designated by the State of Colorado as a Class 2–Warm Water Biota stream (CDPHE 2012b). There are three “tiers” of temperature standards, depending on the assemblage of fish species expected to occur. The Tier III Warm Water stream standards are the least stringent (allowing the warmest water) and should be applied where thermally sensitive species are not expected to occur. Our data show that the Mancos River temperatures were not outside these criteria in 2011. However, because of the historic pres-

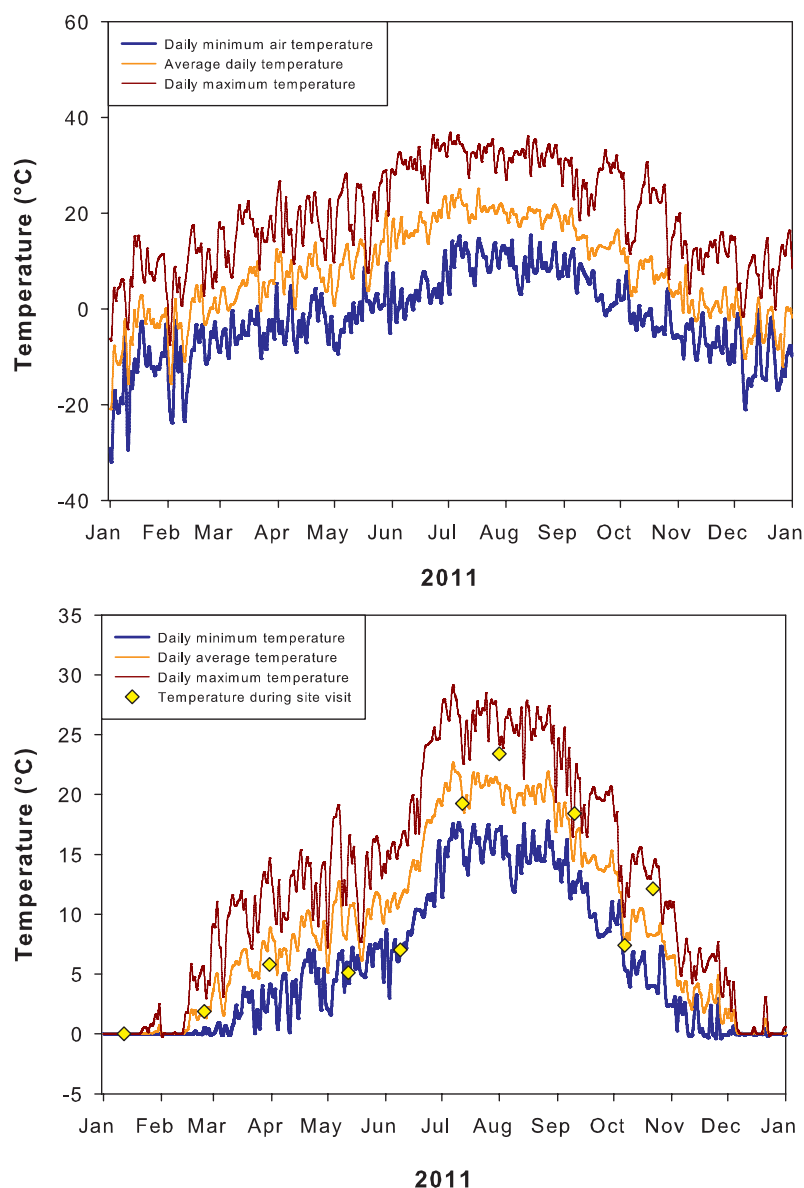


Figure 2. Daily maximum, average, and minimum air temperatures (top) and water temperatures (bottom) recorded at 15-minute intervals by a HOBO Pendant and HOBO TidbiT (Onset Computer Corporation) permanently deployed at MAN01 on the Mancos River in Mesa Verde NP, 2011. Water temperatures recorded during SCPN site visits using a multi-parameter sonde are also shown.

ence of razorback sucker (*Xyrauchen texanus*) within this river reach (San Miguel, G., Natural Resource Manager, Mesa Verde NP, personal communication, 28 July 2011), we also evaluated the temperature against the Tier II Warm Water stream standards. The chronic water temperature criterion is a 27.5°C average over a seven-day period. River temperatures did not exceed this in 2011. The acute water temperature criterion is 28.6°C for more than two hours. This standard was exceeded only once, on July 7.

Measured pH at MAN01 was relatively consistent throughout the year, ranging from 7.9 to 8.4. All measurements were within the water quality criterion of >6.5 and <9.0 (CDPHE 2012b).

Specific conductivity at MAN01 ranged between 282 and 1350 $\mu\text{S}/\text{cm}$, with the highest values observed in the summer. Specific conductivity measurements were lower during the four sampling events from late March through June, when discharge was relatively high. Both pH and specific conductivity were more variable between the months of January and June than they were during the remainder of the year.

Dissolved oxygen ranged between 6.8 and 11.4 mg/L, well within the warm-water standard applicable to MAN01 (5 mg/L, CDPHE 2012b). Measurements were lowest in August, while the highest measured value occurred in January.

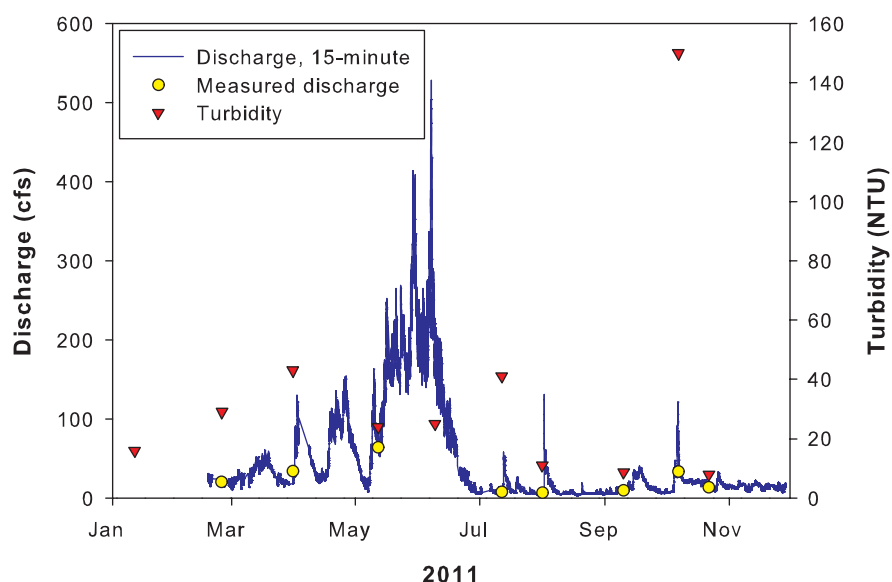


Figure 3. 15-minute streamflow data for the Mancos River from USGS gaging station Mancos River at Anitas Flat below Mancos, CO (09370600) in Mesa Verde NP shows measured discharge (in yellow) and turbidity (in red) for 2011.

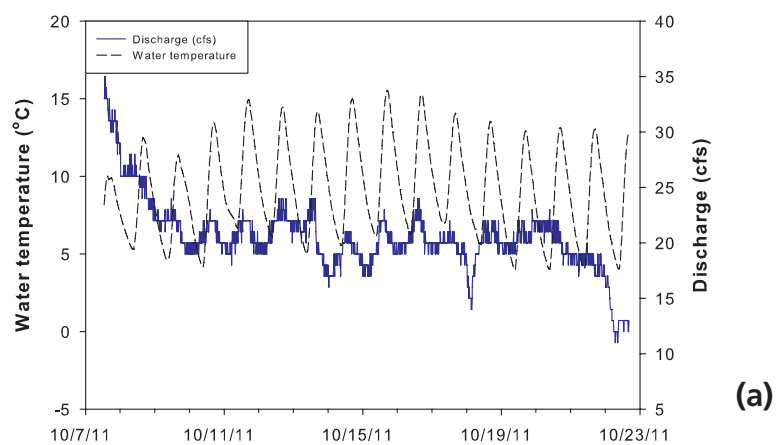
We measured the discharge of the Mancos River during each water quality sampling visit as part of an agreement with the USGS to collect and process data from the streamflow gaging station Mancos River at Anitas Flat below Mancos, CO (09370600) (USGS 2011). Two exceptions were January 12 when the river was frozen, and June 9 when the water level was too high to be measured safely. Measured flows ranged from 6.3 to 64.4 cfs. Figure 3 shows stream discharge plotted with turbidity for 2011. The hydrograph from the gaging station shows large peaks in flow during the May and June snowmelt period preceded by two smaller peaks in April. The highest discharge was 528 cfs on June 7. Turbidity was also higher during this snowmelt period than during the summer base flows. Turbidity levels ranged between 7.9 and 150 NTU; the highest measurement occurred on October 7 after precipitation occurred in the Mancos Valley.

3.2 Temporal variability of water quality core parameter data from the Mancos River in MEVE

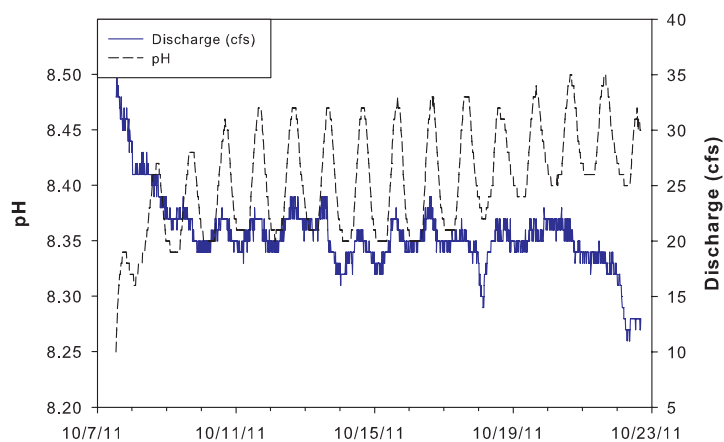
To assess temporal variability in core water quality parameters at MAN01, we deployed a multi-parameter sonde to record data at 30-minute intervals from October 7–22. These data are shown in Figure 4, along with the stream gage data. Significant precipitation, totaling 4.3 cm, occurred in the watershed three days prior to this deployment. Otherwise, the majority of the sampling period was dry with stable stream discharges, ranging from 11 to 35 cfs. Diel fluctuations in temperature averaged 9°C during this deployment. Fluctuations in pH averaged only 0.1 and most measurements were higher than those observed during our site visits in 2011. Dissolved oxygen averaged only 1.8 mg/L and changes in specific conductivity averaged 85 $\mu\text{S}/\text{cm}$. Table 4 summarizes the variability in water temperature, dissolved oxygen, pH, and specific conductivity during the 15-day deployment.

Table 4. Summary of water quality core parameter temporal variability at MAN01 on the Mancos River in Mesa Verde NP, October 7–22, 2011.

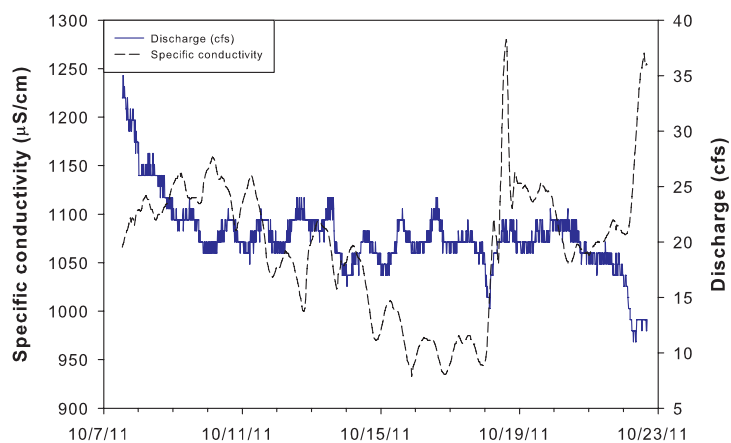
Core parameter	Minimum	Maximum	Median
Water temperature (°C)	3.9	15.5	8.8
Dissolved oxygen (mg/L)	7.9	10.5	9.2
pH	8.3	8.5	8.4
Specific conductivity ($\mu\text{S}/\text{cm}$)	933	1280	1080
Discharge (cfs)	11	35	20



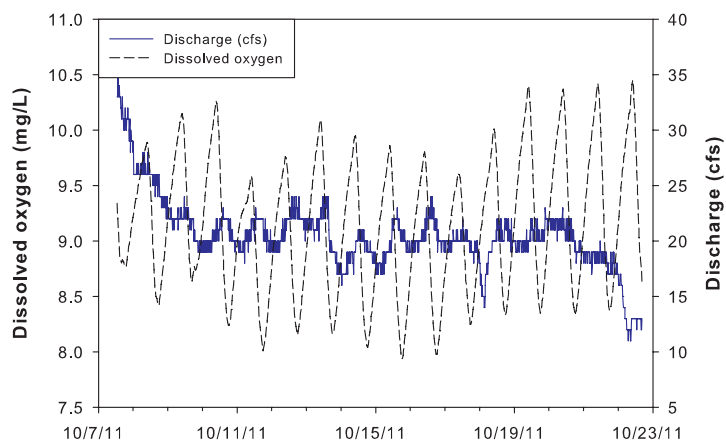
(a)



(b)



(c)



(d)

Figure 4. Multiparameter sonde data measured during a 15-day period from October 7-22, 2011 at MAN01 on the Mancos River in Mesa Verde NP: water temperature (a), pH (b), specific conductivity (c), and dissolved oxygen (d).

3.3 Total coliforms and *E. coli*

Bacteria data collected by SCPN at MAN01 in 2011 are shown in Figure 5 and presented in Appendix B; 2010 data are also included in the graph for comparison. SCPN's data are expressed as a most probable number (MPN) per 100 mL of stream water, a statistical estimate of the number of bacteria. Water quality criteria are expressed as colony forming units (cfu) per 100 mL and do not assume an estimation, but the two units are comparable. The Colorado state criteria values for *E. coli* are based on the geometric mean of at least four evenly-distributed samples collected over a 60-day period. The criteria applicable at MAN01 are 126 cfu/100 mL from May through October and 630 cfu/100 mL from November through April (CDPHE 2012b). We analyze our samples for total coliforms because theoretically they are indicators of the presence of all coliform groups of bacteria, both vegetative and fecal in origin. For drinking water, total coliforms are the standard diagnostic test because their presence indicates contamination of a water supply by an outside source. There are no water quality criteria for total coliforms.

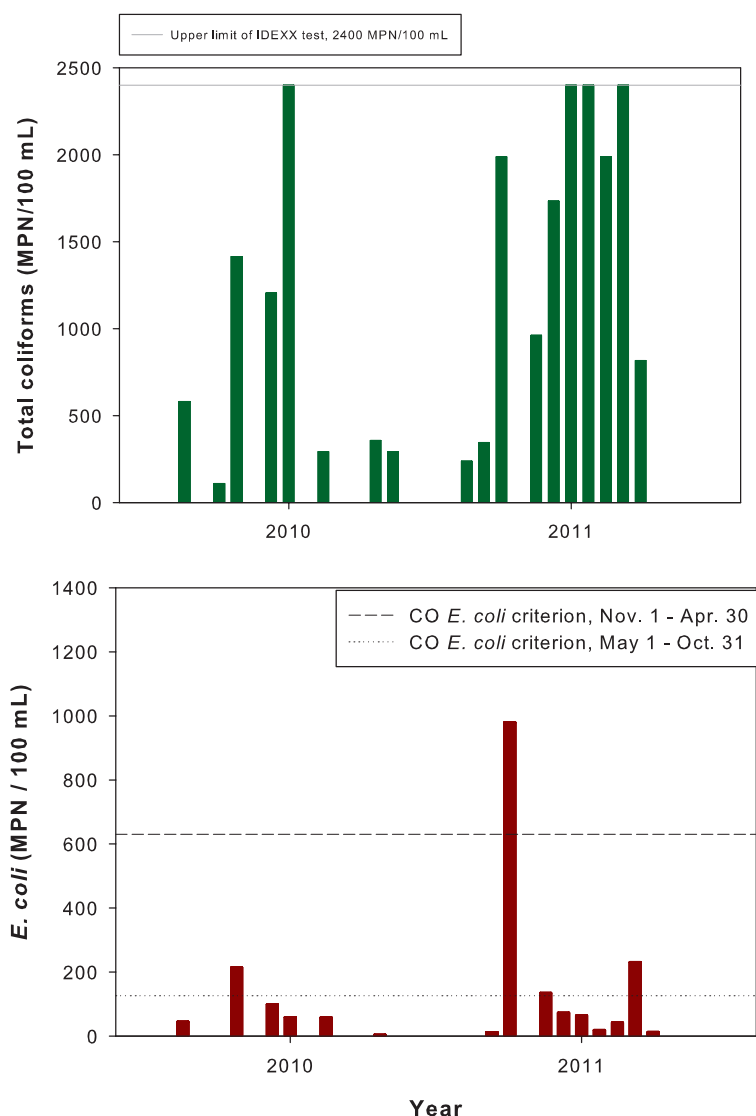


Figure 5. Total coliforms (top) and *E. coli* data (bottom) in samples collected from MAN01 on the Mancos River in Mesa Verde NP, 2010–2011.

E. coli levels were highest in a sample collected on March 31, at 980 MPN/100 mL. *E. coli* also exceeded the Colorado State criterion of 126 MPN/100 mL in May and October, though our sampling was not frequent enough to assess compliance with the water quality standard. The highest total coliform results were from samples collected in July, August, and October. These samples exceeded 2400 MPN/100 mL, the upper limit of the IDEXX test.

3.4 Water quality laboratory data

Seven water samples collected at MEVE by SCPN during 2011 were sent to NWQL to be analyzed for a suite of analytes (Table 1). These samples were collected at regular intervals throughout the year. Laboratory results for water samples are summarized in Tables 5–7; complete results are presented in Appendix B. Analysis of samples collected during 2011 did not exceed the State of Colorado water quality standards.

Nutrient concentrations (Table 5) were very low at all times of the year. Water quality standards exist for ammonia and nitrite, but measurements were well below these criteria. Four of the seven samples for ammonia, nitrite, and nitrite+nitrate were below their corresponding reporting levels. Orthophosphate was detected in six samples; levels remained relatively constant throughout the year, ranging between <0.00400 and 0.00874 mg/L.

Major element data, which includes major anions and cations, silica, acid neutralizing capacity, and total dissolved solids, are summarized in Table 6. Total dissolved solids, which mainly consist of the ions listed in Table 6 plus carbonate/bicarbonate, varied over the year from 356 mg/L to 1090 mg/L, with a median concentration of 1020 mg/L. Figure 6 depicts the major ion composition of the Mancos River during all water sampling events.

Anions mostly consisted of sulfate and, to a lesser extent, bicarbonate. Cation composition was more evenly mixed, with calcium comprising the highest proportion, followed by magnesium, then sodium. Potassium was the least prevalent cation. Major ion composition varied only slightly throughout the year, and 2011 results were very similar to those obtained in 2010.

Table 5. Summary of nutrient data from MAN01 (n=7) on the Mancos River in Mesa Verde NP, 2011, and number of times that the samples exceeded the applicable water quality criteria. A “n/c” indicates that no criteria exists for a particular nutrient. Results that were lower than the National Water Quality Laboratory reporting levels are noted as “<[reporting level]”. All nutrients are dissolved.

Nutrient	Minimum (mg/L)	Maximum (mg/L)	Median ^a (mg/L)	Standard deviation	Criterion (mg/L)	# of exceedances	Beneficial use
Ammonia as N	<0.0100	0.103	---	0.034	n/c	n/c	
Nitrite + nitrate as N	<0.020	0.144	---	0.056	n/c	n/c	
Nitrite as N	<0.00100	0.00495	---	0.0016	0.05	0	Aquatic life
Orthophosphate as P	<0.00400	0.00874	0.0072	0.0021	n/c	n/c	

^a The missing value symbol indicates that the median was not calculated when more than 70% of the results fell below the laboratory reporting level.

Table 6. Summary of major element data from samples collected at MAN01 (n=7) on the Mancos River in Mesa Verde NP, 2011. All major elements are dissolved, except for acid neutralizing capacity. There are no Colorado state water quality criteria for these analytes.

Major element	Minimum (mg/L)	Maximum (mg/L)	Median (mg/L)	Standard deviation
Calcium	58.2	172	157	44
Chloride	3.64	14.9	8.30	3.5
Fluoride	0.095	0.211	0.184	0.043
Magnesium	20.5	72.6	62.9	19.5
Potassium	1.60	3.76	2.94	0.83
Silica	6.91	12.2	9.43	1.8
Sodium	20.7	85.6	50.5	21.3
Sulfate	158	582	530	162
Acid neutralizing capacity, as CaCO ₃ , unfiltered	107	248	200	48
Total dissolved solids	356	1090	1020	291

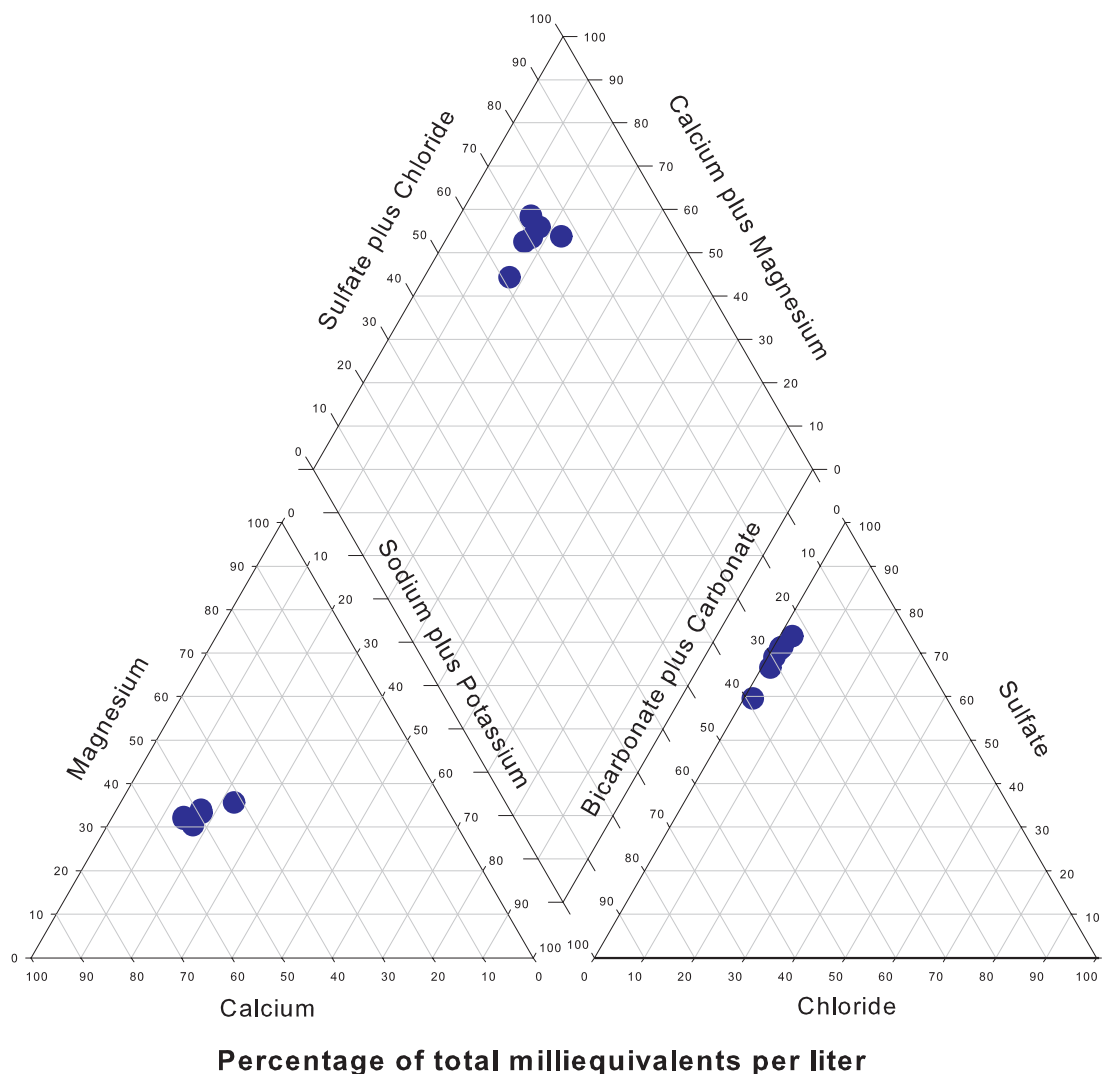


Figure 6. Major ion composition from samples collected at MAN01 on the Mancos River in Mesa Verde NP, 2011.

Table 7 reports the dissolved trace metals analyzed in 2011. All trace metals consistently measured below the water quality criteria, where applicable (CDPHE 2012b). This includes aluminum and selenium, which were outside the chronic aquatic life criterion once each in 2010. The water quality criteria are based on hardness and, because this varied between samples, the actual numeric criteria are expressed as a range where applicable. Mercury, silver, and zinc were not detected above the laboratory reporting level in 2011. Beryllium, cadmium, and chromium were only detected once each, all in July.

3.5 Contaminants of emerging concern

SCPN collected eight water samples at MAN01 from May through October to be analyzed by the EPA Region 8 Laboratory for a suite of 206 contaminants of emerging concern. The complete dataset is in Appendix B, and detections for 18 contaminants, all in ng/L concentrations, are summarized in Table 8. Of these, only nonylphenol, pentachlorophenol, naphthalene, and fluoranthene have water quality standards assigned to them. Our results are well below these criteria, as the criteria are listed in µg/L (nonylphenol and pentachlorophenol) and mg/L (naphthalene and fluoranthene).

Table 7. Summary of trace metal data from samples collected at MAN01 (n=7) on the Mancos River in Mesa Verde NP, 2011, and number of times that the samples were outside the applicable water quality criterion. A “n/c” indicates that no dissolved criterion exists for a particular trace metal. Results that were lower than the NWQL reporting levels are noted as “<[reporting level]”

Trace metal, dissolved	Minimum (µg/L)	Maximum (µg/L)	Median ^a (µg/L)	Standard deviation ^a	Criterion (µg/L)	# of exceedances	Beneficial use
Aluminum	<1.70	72.1	2.89	28.7	n/c	n/c	
Antimony	0.0961	0.134	0.109	0.013	n/c	n/c	
Arsenic	0.290	1.03	0.348	0.27	150 (chronic)	0	aquatic life
Barium	41.4	56.9	47.2	5.6	n/c	n/c	
Beryllium	<0.0060	0.0078	---	---	n/c	n/c	
Boron	17.9	72.4	41.8	21.7	750, 30 day	0	agriculture
Cadmium	<0.016	0.022	---	---	0.80–1.20 (chronic)	0	aquatic life
Chromium	<0.060	0.075	---	---	141 (Cr(III), 11 Cr(IV) (chronic)	0	aquatic life
Cobalt ^b	0.385	0.787	0.577	0.137	n/c	n/c	
Copper	1.19	5.46	1.49	1.58	18.3–29.3	0	aquatic life
Iron ^b	6.7	156	10.0	54	n/c	n/c	
Lead	<0.0150	0.155	0.0272	0.050	6.18–10.9 (chronic)	0	aquatic life
Manganese ^b	17.3	78.6	44.8	23.6	2180–2618 (chronic)	0	aquatic life
Mercury	<0.005	<0.005	---	---	n/c	n/c	
Molybdenum ^b	0.882	2.69	2.16	0.71	n/c	n/c	
Nickel	0.947	2.35	1.80	0.5	106–168 (chronic)	0	aquatic life
Selenium	0.59	2.57	1.17	0.67	4.6 (chronic)	0	aquatic life
Silver	<0.0050	<0.0050	---	---	1.35–3.47 (chronic)	0	aquatic life
Uranium	1.11	5.15	3.96	1.43	3776–6915 (chronic)	0	aquatic life
Vanadium	0.112	0.614	0.216	0.169	n/c	n/c	
Zinc	<1.40	<1.40	---	---	259–428	0	aquatic life

^a Values not reported were not calculated because more than 70% of results were below the laboratory reporting level.

^bResults of a field blank indicated contamination with small concentrations of cobalt (0.0464 µg/L), iron (4.37 µg/L), manganese (0.154 µg/L), and molybdenum (0.0338 µg/L). Therefore, we have flagged all results for these trace metals except for those that fell below the NWQL reporting levels.

Table 8. Summary of detections of contaminants of emerging concern in samples collected at MAN01 (n=8) on the Mancos River in Mesa Verde NP, 2011.

Contaminant	Use	# of detections
Pharmaceuticals and personal care products		
Metformin	Type-2 diabetes drug used to control blood glucose	5
Gabapentin	anticonvulsant, painkiller	7
Gemfibrozil	cholesterol medication	1
Waste indicators		
Bisphenol A	used in the production of polycarbonate plastics and epoxy resins (hard plastic bottles and metal food cans)	3
Tri(dichloroisopropyl) phosphate	flame retardant in foams, resins, and latexes	2
17 beta-estradiol	estrogenic hormone, used in pharmaceuticals	2
Camphor	odorant, flavorant, plasticizer, cosmetics, preservative	3
Nonylphenol	breakdown product from detergents	3
Tri (2-butoxyethyl) phosphate	flame retardant, plasticizer in rubber and plastics, used in floor polishes	2
<i>p</i> -cresol	solvent, disinfectant, and chemical intermediate	2
Triclosan	antimicrobial ingredient	1
Naphthalene	produced during coal and oil combustion, used in the manufacture of PVC plastics, used in mothballs	1
Pentachlorophenol	formerly a widely-used pesticide, wood preservative	2
Methyl salicylate	fragrance	1
Carbazole	produced during coal combustion, used to make dyes	1
Pesticides		
Propachlor OA	herbicide	1

4 Quality assurance/Quality control

We followed the Quality Assurance/Quality Control procedures described in Monroe et al. (in preparation) and in National Park Service 2012. Prior to each sampling event, the multiparameter sondes were calibrated, maintained, and compared to one another indoors. The streamflow current meter was checked to be in proper working order according to manufacturer recommendations, and the turbidimeter was checked for calibration drift in the lab prior to each sampling event and in the field prior to each measurement. Fifteen duplicate bacteria samples were collected at several SCPN monitoring sites by filling two sample bottles in succession and comparing tray results after the incubation period. Thirteen blank samples were processed using sterile water provided by IDEXX. To verify the cleanliness of both the sampling equipment and the sample filtration process for nutrients, major elements, and trace metals, NWQL analyzed one sample set of certified inorganic blank water at the end of 2011.

In December 2011, SCPN sent one set of samples with certified inorganic blank water to NWQL for nutrients, trace metals, and major elements. Most analytes were not detected, but four trace metals were detected at low concentrations: cobalt (0.0464 µg/L), iron (4.37 µg/L), manganese (0.154 µg/L), and molybdenum (0.0338 µg/L); indicating possible contamination during the processing of the field samples. At MEVE, most detections were significantly lower than the field samples reported in tables 5–7 and appendix B; however, blank results were within 10% of the following stream sample results for iron: 8.8, 8.9, 6.7, 31.1, 10, and 20.1 µg/L; and cobalt: 0.385 and 0.453 µg/L.

5 Summary

In 2010, SCPN implemented long-term water-quality monitoring at MAN01 on the Mancos River in MEVE. Data collected during ten site visits to MAN01 in 2011 is summarized here and compared against applicable Colorado water quality standards (CDPHE 2012a,b).

We made site visits at regular intervals throughout the year, capturing a variety of different seasonal and flow conditions. Discharge at the time of sample events ranged from 6.3 to 213 cfs. Turbidity ranged from 7.9–150 NTU. Specific conductivity ranged from 345–2210 µS/cm. Dissolved oxygen measurements ranged from 6.8–11.4 mg/L. Measured pH was between 7.9 and 8.4. Water temperatures were logged at 15-minute intervals year-round and did not exceed the chronic water temperature criterion, but exceeded the acute criterion of 28.6°C for one day in July, 2011. A long-term sonde deployment at MAN01 during a hydrologically stable 15-day period showed regular diurnal patterns in water temperature, dissolved oxygen, pH and specific conductivity.

Results of SCPN's analyses for total coliforms in 2011 ranged from 240 MPN/100 mL in January to >2400 MPN/100mL, the upper limit for the analysis method used, in July, August, and October. Results of analyses for *E. coli* ranged from <1 MPN/100 mL in January to 980 MPN/100 mL in March. The sample collected in March, as well as results for samples collected in May and October, all exceeded the State of Colorado's water quality criteria for *E. coli*. SCPN's sampling strategy is not designed to assess compliance with water quality standards and further sample collection would be required to make a definite determination.

Laboratory-measured results for nutrients and trace metals were below applicable water quality criteria. Mercury, silver, and zinc were not detected in any of the seven samples. Major ion analyses show that the water at MAN01 is dominated by sulfate and calcium. Total dissolved solids were generally high, except during spring snowmelt, and ranged from 356 to 1090 mg/L, with a median of 1020 mg/L. Acid neutralizing capacity was also lower during the spring snowmelt period; CaCO₃ values ranged from 107 to 248 mg/L with a median of 200 mg/L.

The data in this report should be viewed as a snapshot of water quality conditions existing at the time that the data was collected. Data and analyses in this report are provisional and are subject to change. When sufficient data are available, SCPN plans to produce an interpretive report which will include trend analysis of water quality data for the Mancos River in Mesa Verde National Park.

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Appendices

Appendix A: Southern Colorado Plateau Network water quality monitoring sites

Table A1. Southern Colorado Plateau water quality monitoring sites for Mesa Verde National Park, 2011.

Site code	Common name	Report name	Northing (m) ¹	Easting (m) ¹	Elevation (m) ¹
MEVEMAN01	Mancos River at Gage	MAN01	4126163	734375	1933
MEVEMAN02	Mancos River above downstream boundary	MAN02	4122566	735878	1882

¹ Horizontal coordinates are reported in Universal Transverse Mercator (UTM) Projection, Zone 12, North American Datum of 1983 (NAD 83). Vertical coordinates are referenced to the North American Vertical Datum of 1988 (NAVD 88).

Appendix B: Water quality monitoring results for the Mancos River at Mesa Verde National Park, 2011

Table B1. Water quality core parameter data from MAN01 on the Mancos River in Mesa Verde NP, 2011.

Parameter	Unit	Sample collection date and time									
		1/12 11:37	2/24 12:51	3/31 10:52	5/12 9:30	6/9 9:00	7/12 11:00	8/1 15:10	9/10 17:00	10/7 12:50	10/22 18:15
Water temperature	°C	0.0	2.2	6.5	5.3	7.0	19.3	23.4	18.4	7.4	12.1
pH	none	7.9	8.3	8.3	8.1	8.0	8.4	8.2	8.3	8.3	8.3
Specific conductivity	μS/cm	1280	1300	777	497	282	1350	1350	1320	1060	1250
Dissolved oxygen	mg/L	11.4	10.7	10.0	9.5	9.6	7.7	6.8	7.6	9.5	8.1
Turbidity	NTU	16	29	43	24	25	41	11	8.6	150	7.9
Discharge	cfs	ice	20.3	33.8	64.4	213	7.6	6.3	9.7	33.4	13.3

Table B2. Total coliforms and *E. coli* in samples collected at MAN01 on the Mancos River in Mesa Verde NP, 2011.

Parameter	Unit	Sample collection date and time									
		1/12 11:37	2/24 12:51	3/31 10:52	5/12 9:30	6/9 9:00	7/12 11:00	8/1 15:10	9/10 17:00	10/7 12:50	10/22 18:15
Total coliforms	MPN/100 mL	240	340	2000	960	1700	>2400 ^a	>2400 ^a	2000	>2400 ^a	820
<i>E. coli</i>	MPN/100 mL	<1	12	980	140	73	64	19	43	230	13

^a Exceeded the maximum detection level of IDEXX system, which is 2400.

Table B3. Results of laboratory analyses for samples collected from MAN01 on the Mancos River in Mesa Verde NP in 2011. Samples were analyzed by the U.S. Geological Survey National Water Quality Laboratory (NWQL). Results that were lower than the NWQL reporting levels are noted as "<[reporting level]". All analytes were dissolved, except acid neutralizing capacity.

Analyte	Sample collection date and time						
	1/12	2/24	3/31	5/12	7/12	9/10	10/22
	11:37	12:51	10:52	9:30	11:00	17:00	18:15
Nutrients (mg/L)							
Ammonia as N	0.103	0.0347 ^a	<0.0100	0.0158	<0.0100	<0.0100	<0.0100
Nitrite + nitrate as N	0.144	0.131 ^a	<0.020	0.050	<0.020	<0.020	<0.040
Nitrite as N	0.00495	0.00312 ^a	<0.00100	0.00311	<0.00100	<0.00100	<0.00100
Orthophosphate as P	0.00721	0.00874 ^a	0.00430	0.00849	0.00856	0.00487	<0.00400
Major elements (mg/L)							
Calcium	157	140	92.2	58.2	161	172	170
Chloride	10.3	14.9	5.97	3.64	8.30	8.67	8.18
Fluoride	0.175	0.184	0.142	0.095	0.202	0.211	0.211
Magnesium	64.3	72.6	33.9	20.5	67.6	62.9	61.3
Potassium	2.66	2.94	1.93	1.60	3.76	3.61	3.35
Silica	9.43	8.02	6.91	8.64	10.9	12.2	10.4
Sodium	61.5	85.6	30.9	20.7	61.2	50.4	50.5
Sulfate	545	582	287	158	556	530	494
Acid neutralizing capacity, as CaCO ₃ (unfiltered)	214	194	142	107	248	211	200
Total dissolved solids	1030	1090	562	356	1080	1020	961
Trace metals (µg/L)							
Aluminum	<1.70	2.02	12.2	49.8	72.1	2.16	2.89
Antimony	0.0985	0.108	0.119	0.109	0.134	0.116	0.0961
Arsenic	0.290	0.342	0.344	0.348	1.03	0.696	0.518
Barium	49.9	46.0	42.8	41.4	56.9	47.2	53.7
Beryllium	<0.0060	<0.0060	<0.0060	<0.0060	0.0078	<0.0060	<0.0060
Boron	41.8	41.8	24.3	17.9	71.9	72.4	59.0
Cadmium	<0.016	<0.016	<0.016	<0.016	0.022	<0.016	<0.016
Cobalt ^b	0.486	0.577	0.787	0.629	0.385	0.453	0.655
Copper	1.49	1.37	3.42	5.46	2.29	1.32	1.19
Chromium	<0.060	<0.060	<0.060	<0.060	0.075	<0.060	<0.070
Iron ^b	8.8	8.9	6.7	31.1	156	10.0	20.1
Lead	0.0261	<0.0150	0.0272	0.0516	0.155	0.0345	<0.0250
Manganese ^b	78.6	67.4	44.8	17.3	25.9	24.5	57.6
Mercury	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Molybdenum ^b	1.67	2.16	1.13	0.882	2.57	2.69	2.32
Nickel	1.67	1.80	1.31	0.947	2.14	1.98	2.35
Selenium	1.51	2.57	0.656	0.590	1.17	1.65	1.17
Silver	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Uranium	4.20	5.15	1.80	1.11	3.66	4.03	3.96
Vanadium	0.112	0.186	0.177	0.216	0.614	0.364	0.256
Zinc	<1.40	<1.40	<1.40	<1.40	<1.40	<1.40	<1.40

^a Nutrient samples arrived warm (7°C) to the NWQL, nutrients should be kept <4°C.

^b Results of a field blank indicated contamination with small concentrations of cobalt (0.0464 µg/L), iron (4.37 µg/L), manganese (0.154 µg/L), and molybdenum (0.0338 µg/L).

Table B4. Contaminant of emerging concern detections in samples collected at MAN01 on the Mancos River in MEVE, 2011. All results are in ng/L. Analytes listed in this table were detected at least once during the 2011 monitoring season. In those instances where the analyte was not detected above the reporting level, the table cell is left blank. Only a few of the analytes had Colorado state aquatic life criteria, and none exceeded these criteria. A duplicate sample was taken on July 12, 2011 for quality control.

Analyte	Reporting limit	Sample collection date and time							
		5/12	6/9	7/12	7/12	8/1	9/10	10/7	10/22
		9:30	9:00	11:00	11:00	15:10	17:00	12:50	18:15
Pharmaceuticals and personal care products									
Metformin	10.0	101 ^{a,b}	13.9			27.4		22.2	38.5
Gabapentin	25.0	233 ^{a,b}	116 ^b	50.7 ^b	54.0 ^b		137 ^b	501 ^d	447 ^b
Gemfibrozil	10.0							11.2	
Waste indicators									
Bisphenol A	50.0		115 ^c	180				79.6	
Tri(dichloroisopropyl) phosphate	50.0		66.4 ^c		51.8				
17beta-estradiol	50.0		87.0 ^c	123 ^c					
Camphor	50.0			57.2	85.5			53.8	
Nonylphenol ^e	50.0			97.7	168			90.4	
Tri(2-butoxyethyl) phosphate	50.0			292			224		
<i>p</i> -cresol	50.0				57.8				79.2
Triclosan	50.0				72.5				
Naphthalene ^f	50.0							53.4	
Pentachlorophenol ^g	50.0							83.4	424
Methyl salicylate	50.0							91.2	
Carbazole	50.0								58.8
Pesticides									
Propachlor OA	10.0		16.5						

^a Samples were analyzed outside of holding time - all results are estimated values

^b Laboratory calibration acceptance criteria not met - all results are estimated values

^c Laboratory QA/QC acceptance criteria not met - all results are estimated values

^d Laboratory matrix spike acceptance criteria not met, result is estimated

^e Colorado state aquatic life criteria for Nonylphenol are: acute=28,000 ng/L, chronic=6,600 ng/L

^f Colorado state aquatic life criteria for Naphthalene are: acute=2,300,000 ng/L, chronic=620,000 ng/L

^g Colorado state aquatic life criteria for Pentachlorophenol are: acute=19,000 ng/L, chronic=15,000 ng/L

Appendix C. List of analytes and reporting limits for contaminants of emerging concern

Table C1. Target analytes and U.S. Environmental Protection Agency reporting limits for pesticides.

Analyte	Reporting limit (ng/L)	Analyte	Reporting limit (ng/L)
2,4,5-T	10	EPTC	20
2,4,5-TP	10	Ethoprop	10
2,4-D	10	Fipronil	20
3-Hydroxycarbofuran	10	Fipronil sulfide	10
Acetochlor	20	Hexazinone	10
Acetochlor OA	20	Imazaquin	20
Alachlor	20	Imazethapyr	10
Alachlor OA	50	Imidacloprid	20
Aldicarb	10	Linuron	20
Aldicarb sulfone	20	Malathion	10
Aldicarb sulfoxide	10	MCPP	20
Atrazine	10	Metaxyl	10
Atrazine de-ethyl	20	Methiocarb	10
Atrazine de-isopropyl	20	Methomyl	20
Atraton	50	Metolachlor	10
Azoxystrobin	20	Metolachlor ESA	20
Bentazon	10	Metribuzin	20
Bromacil	50	Monuron	10
Bromoxynil	10	Neburon	50
Butachlor ESA	10	Oryzalin	20
Carbaryl	10	Oxamyl	10
Carbofuran	10	Pentachlorophenol	50
Chlorimuron ethyl	20	Prometon	10
Cyanazine	10	Propachlor	10
3-Hydroxycarbofuran	10	Propachlor ESA	20
Dacthal monoacid	20	Propazine	50
Diazinon	10	Propiconazole	20
Dichloroprop	10	Propoxur	10
Dimethachlor	10	Simazine	20
Dimethenamid	10	Sulfometuron methyl	20
Dimethenamid ESA	20	Tebuconazole	50
Disulfoton sulfone	20	Tebuthiuron	10
Diuron	50	Terbuthylazine	10
Diuron Metabolite	50	Thiamethoxam	20

Table C2. Target analytes and reporting limits for pharmaceuticals and personal care products

Analyte	Reporting limit (ng/L)	Analyte	Reporting limit (ng/L)
Acebutolol	10.0	Fenbufen	10.0
Albuterol	10.0	Fentanyl	10.0
Alprazolam	10.0	Flunitrazepam	10.0
Amitriptyline	10.0	Furosemide	10.0
Amitriptyline, (+/-)-E-10-hydroxylated	10.0	Gabapentin	25.0
Amphetamine	10.0	Gemfibrozil	10.0
Atenolol	10.0	Glipizide	10.0
Atrazine	10.0	Glyburide	10.0
Benzoyllecgonine	10.0	Hydrocodone	10.0
Benzphetamine	10.0	Hydromorphone	10.0
Bezafibrate	10.0	m-Hydroxybenzoyllecgonine	10.0
Brombuterol	10.0	Ibuprofen	10.0
Butabarbital	25.0	Levorphanol	10.0
Butalbital	10.0	Loratadine	10.0
n-Butylparaben	25.0	Mefenamic acid 3-carboxy	10.0
Carbamazepine 10,11 epoxide	10.0	MDA	10.0
Caffeine	10.0	MDEA	10.0
Cannabidiol	25.0	MDMA	10.0
Cannabinol	25.0	Meperidine	10.0
Carbamazepine	10.0	Mephobarbital	25.0
Carisoprodol	10.0	Meprobamate	10.0
Chloramphenicol	10.0	Metformin	10.0
Chlordiazepoxide	10.0	Methamphetamine	10.0
Chlorpheniramine	10.0	Methaqualone	10.0
Cimetidine	10.0	Methylparaben	10.0
Clenbuterol	10.0	Methypylon	10.0
Clobazam	10.0	Metoprolol	10.0
Clonazepam	10.0	Monensin	10.0
Clonidine	10.0	Morphine	10.0
Cocaethylene	10.0	Naproxen	10.0
Cocaine	10.0	Nifedipine	10.0
Codeine	10.0	Nifedipine oxidized	10.0
DEET	10.0	Nitrazepam	10.0
Dextromethorphan	10.0	Norfentanyl	10.0
Diazepam	10.0	Norfluoxetine	10.0
Diclofenac	10.0	Norverapamil	10.0
Diltiazem	10.0	Omeprazole	10.0
Diphenhydramine	10.0	Oxycodone	10.0
Ecognine Methyl Ester	10.0	Oxymorphone	10.0
Erythromycin	10.0	Paroxetine	10.0
Famotidine	10.0	Pentazocine	10.0
Fenbendazole	10.0	Phencyclidine	10.0

Table C2. Target analytes and U.S. Environmental Protection Agency reporting limits for pharmaceuticals and personal care products, *continued*

Analyte	Reporting limit (ng/L)	Analyte	Reporting limit (ng/L)
Phenmetrazine	10.0	Temazepam	10.0
Phenobarbital	10.0	Testosterone	10.0
Phentermine	10.0	(+/-)11-nor-9-carboxy-delta-THC	10.0
Phenylpropanolamine	10.0	THC	25.0
Phenytoin	10.0	Thebaine	10.0
Pindolol	10.0	Thiabendazole	10.0
Prazepam	10.0	Tramadol	10.0
Progesterone	10.0	Trazodone	10.0
Propranolol	10.0	Triamterene	10.0
Pseudoephedrine	10.0	Triazolam	10.0
Ranitidine	10.0	Triclocarban	10.0
Secobarbital	10.0	Triclosan	10.0
Sildenafil	10.0	Trimethoprim	10.0
Simvastatin	10.0	Tylosin	10.0
Sotalol	10.0	Venlafaxine	10.0
Sulfamethazine	10.0	Verapamil	10.0
Sulfamethoxazole	10.0	Warfarin	10.0
Talbutal	25.0		

Table C3. Target analytes and U.S. Environmental Protection Agency reporting limits for wastewater indicators.

Analyte	Reporting limit (ng/L)	Analyte	Reporting limit (ng/L)
Acetophenone	50.0	17beta-Estradiol	50.0
Benzophenone	50.0	Estrone	50.0
Bisphenol A	50.0	Ethynylestradiol	50.0
Bromacil	50.0	Fluoranthene	50.0
Butylated Hydroxyanisole	50.0	Galaxolide	50.0
Caffeine	50.0	Indole	50.0
Camphor	50.0	Isoborneol	50.0
Carbaryl	50.0	Isophorone	50.0
Carbazole	50.0	Isoquinoline	50.0
Celestolide	50.0	Menthol	50.0
Chlorpyrifos	50.0	3-Methyl Indole	50.0
p-Cresol	50.0	Methyl Salicylate	50.0
4-Cumylphenol	50.0	2-Methylnaphthalene	50.0
Dacthal	50.0	1-Methylnaphthalene	50.0
Diazinon	50.0	2,6-Dimethylnaphthalene	50.0
1,4-Dichlorobenzene	50.0	Metolachlor	50.0
Dichlorvos	50.0	Musk ketone	50.0
Equilenin	50.0	Naphthalene	50.0
Nonylphenol	50.0	Tonalide	50.0
4-n-Octylphenol	50.0	Tributyl Phosphate	50.0
4-tert-Octylphenol	50.0	Triclosan	50.0

Table C3. Target analytes and U.S. Environmental Protection Agency reporting limits for wastewater indicators
continued

Analyte	Reporting limit (ng/L)	Analyte	Reporting limit (ng/L)
Pentachlorophenol	50.0	Tri(dichloroisopropyl) Phosphate	50.0
Phantolide	50.0	Triethyl Citrate	50.0
Phenanthrene	50.0	Tri(2-butoxyethyl) Phosphate	50.0
Phenol	50.0	Tri(2-chloroethyl) Phosphate	50.0
Prometon	50.0	Triphenyl phosphate	50.0
Pyrene	50.0		

Appendix D. Abbreviations, chemical formulas, and symbols used in this report

Term	Definition
CaCO ₃	chemical formula for calcium carbonate
cfs	cubic feet per second
cfu/100 mL	colony forming units, for bacteria sampling, a measure of the number of viable bacteria per 100 mL
µg/L	micrograms per liter, equivalent to one part per billion
µS/cm	microsiemens per centimeter at 25°C, a measure of specific conductivity
mg/L	milligrams per liter, equivalent to one part per million
Milliequivalents per liter	an expression of the concentration of substances that is chemically equivalent in terms atomic weight and electrical charge
MPN/100 mL	most probable number, for sampling bacteria, a statistical estimation of the number of coliforms that would give the results shown by the laboratory examination
N	chemical symbol for the element nitrogen
ng/L	nanograms per liter, equivalent to one part per trillion
NTU	nephelometric turbidity unit, a measure of turbidity
P	chemical symbol for the element phosphorous

Appendix F

SCPN Water Quality Monitoring Equipment List

Equipment to bring for the field

Basic field supplies
Digital camera
GPS (recreational grade)
Extra batteries for all equipment
Multi-tool
Compass
Watch
Rope
Field notebook
Park keys
Personal and group safety
First aid kit
Satellite phone, Spot, cell phone, or park radio
Personal items
Rain gear
Sunhat
Sandals, waders, hip boots or other water shoes
Hiking boots
Drinking water
Sunscreen
Headlamp
Site specific equipment (SOP #3)
Site description, map, and/or coordinates
All necessary permits (research, backcountry, and camping)
Equipment list
Park contact information
Emergency contact information
Photographs
Relevant notes from previous sampling efforts
Field office
Pencils
Permanent marker
Field datasheets on waterproof paper
Clipboard
Calculator

Waterproof labels
Sample collection gear, per sample (SOP #s 6, 8)
Water chemistry sample bottles, rinsed (1 glass, 2 black capped plastic, 1 acid-rinsed white capped plastic 250 mL bottles, 1 brown 125 mL bottle)
Bacteria bottle (sterile 120 mL)
Turbidity bottle
White powder free disposable gloves, 1 pair per person
Collapsible cooler
Bag of ice
Small drill with drill bit
Peristaltic pump
Peristaltic pump tubing
Blank water, 1L
Deionized water 1L
0.45 µm high capacity filter
Preservation acids, HCl and HNO ₃
Water quality meters (SOP #5)
Hydrolab with cable, flow-cap, and end-cap
Hanna Combo meter (HI98129)
Turbidimeter with Gelex standards and turbidity sample cells
PDA
Mesh bag with calibration solutions in 125 mL bottles (for most streams: pH 7, pH 10, SC 100, SC 1413)
De-ionized water, 125 mL
Thermometer
Barometer
Plastic bottle for LDO calibration, 0.5L
Spare batteries, 10 AA
Flow (SOP #5)
Site-appropriate flow meter
Appropriate wading rod for each meter with parts
Measuring tape and clips
Spare batteries (8 AA for FlowTracker, 2 9-volt for Aquacalc, 2 D for Marsh-McBirney)
Temperature logger (SOP #5)
Laptop
Hobo Waterproof Shuttle or Optic USB Base Station
Spare temperature loggers
Spare batteries (CR2032)
Small zip ties and cord
Small screwdriver

Equipment to keep in the vehicle

Bacteria sample processing gear (SOP #7)

Colilert-18 or -24

Tray sealer with inverter

Quanti-trays

Incubator with inverter and wall plug

UV lamp

White powder free disposable gloves

Processing chamber with clear plastic bags (if not filtering samples in the field)

Sterile water

Decontamination (Appendix C)

Sprayer with decontamination solution

Other

Coolers

Drill charger

Spare batteries for all equipment

Cigarette lighter inverter

Laptop charger

Laboratory equipment

Care and cleaning of water sample bottles and tubing (SOP 6)

Item	Descriptions and comments
Bags, plastic or fluorocarbon	Sealable bags with uncolored closure strips, various sizes. Polymer. Recyclable trash bags are recommended for large equipment storage.
Non-colored plastic sheeting	Clean sheeting used to provide a clean work surface.
Brushes and sponges	Uncolored; plastic components needed for inorganic work.
Deionized water	Usable only as a cleaning solution and only as specified in the text.
Detergent	Nonphosphate laboratory soap (for example, Liquinox®).
Gloves, disposable	Powderless, noncolored vinyl or nitrile.
Tap water	If quality is questionable, substitute DIW. Tap water is more effective for initial and rapid removal of detergent residue.
Tissues	Laboratory grade, lint free, various sizes (for example, Kimwipes™).
Wash basins	One wash basin dedicated for soaking in soap, one dedicated for acid soak. White or uncolored, plastic, nonleaching.
Drying racks	For drying equipment. Should be stored in clean plastic bags in between washings

Wash bottles (dispenser or squeeze)	Filled with DIW, stored in clean plastic bag
Hydrochloric acid	Trace metal grade
Safety goggles and lab coat	
Baking soda	In sufficient quantity to neutralize all acid in the laboratory
Spill kit	Sufficient to neutralize and absorb any acid spills: broom and dustpan, baking soda, vermiculite, gloves, trash bags
Equipment maintenance (SOP 4)	
Equipment log books	
Operating manuals	
Hydrology premobilization datasheets	
Calibration solutions	pH 4, pH 7, pH 10, SpC 100, SpC 1413, SpC 5000
KCl reference electrolyte solution	
KCl salt tablets	
Turbidity standards	Set of 4: <1, 20, 100, and 800 NTU
Sodium sulfite	
Cobalt chloride	
NIST-certified thermometer	0.1°C graduated; calibrated accuracy of 0.1°C
Sample shipment supplies (SOP 11)	
Clear packing tape	
Plastic trash bags	
Ice	
FedEx shipping pouches	
Cooler	
Laboratory forms	

Appendix G

Using a Digital Camera for Photopoint Monitoring

Standard Operating Procedure #9 (Photopoint Monitoring) of the *Water Quality Monitoring Protocol for Streams and Springs in the Southern Colorado Plateau Network* assumes the use of digital cameras to record photo data in the field. While digital cameras provide several advantages over film cameras (primarily with instant feedback, and more convenient file management) they do present some challenges.

Choosing a camera

In the days of film photography, photos taken from the same spot and in the same direction by any 35mm (common film size) camera with any equal size lens (i.e. 28mm, 50mm, etc.) would result in almost identical images. However, digital cameras use a variety of sensor sizes that can show dramatically different perspectives from similar sized lenses due to the interaction of sensor size with a lens's focal length. To try and overcome this confusion, digital camera manufacturers will often list their cameras focal lengths in 35 mm equivalents in their advertising. For instance, a digital camera with a 7.7mm sensor and a 5.4mm to 54mm zoom lens would take pictures that look similar to a 35mm film camera with a 30-300mm zoom lens. Unfortunately they usually do not list this equivalent on the camera itself.

Ideally the same camera used at the same zoom settings would be used on all repeat visits to a particular site. This is unlikely to happen over time, so steps should be taken to ensure that the photos look as similar as possible between visits. The best way to do this is to utilize photos from previous visits and adjust the camera's zoom and/or your position in order to match the framing of the original photo.

Due to the tight confines of many water quality monitoring sites, it is recommended that a camera with a 30mm or wider (e.g. 28mm, 24mm) field of view (in 35mm equivalent) be used. Cameras with a narrower field of view (35mm, 40mm, etc.) can have a hard time capturing a wide enough area to best show local conditions, especially in dense riparian areas or narrow canyons.

Cameras with lenses with very large zoom ranges (8x or greater) can often produce lower quality pictures than cameras with smaller range zooms (4x or less). These differences are often most obvious at the wide angle setting where most monitoring photos are taken. Make sure that cameras selected for monitoring take sharp enough pictures at the wide angle setting—look especially at the corners of photographs where some lenses can show distinct out of focus (fuzzy looking) areas, as well as distorted areas where straight lines bend dramatically inward. If the only available camera takes poor photos at its widest setting, then zooming in a little bit can often result in a noticeably sharper image.

Digital cameras have a wide range of image quality and file sizes that depend on the size of the imaging sensor, number of pixels on the sensor, and the quality of the lens. Sensor quality is measured in megapixels but more megapixels often do not mean a higher quality picture. Most quality digital cameras with an 8 megapixel or better sensor should be able to take pictures with adequate detail for photopoint monitoring. However, cameras should be tested before being brought into the field to ensure that they produce images of adequate quality and to determine what settings need to be used to maintain that quality.

Taking quality photographs

Images are usually stored on the camera's memory card as compressed JPEGs. Various settings in the camera can affect the final quality of the image file. Compression ratios influence file size, with more compression reducing file size, but resulting in lower quality photos. Consult the camera user's manual for details on setting the compression ratio, and select a ratio adequate to capture the level of detail needed to compare changing conditions over time without creating file sizes that are unnecessarily large.

Due to the small size of digital camera sensors most digital cameras can easily take photos where both the foreground and background are in focus. The area of the picture in focus is known as the Depth of field. Different settings in the camera as well as the point the camera is focused on can affect the depth of field. Using the camera in its standard or landscape mode should create a wide enough depth of field in the image. Make sure that the camera is not focusing on objects too close which would make mid and far range objects look out of focus. In situations with objects very close and very far from the camera, try locking the camera's focus (see camera's user manual) on different areas to make sure the important areas of the photo are in focus (Figure G-1).

Most digital cameras do an adequate job of automatically determining proper exposure for the photograph under a variety of conditions. Some conditions, such as the sun in the frame or areas of bright sky and shaded foreground, can make it hard to impossible to take a useful photograph. In these cases try locking the exposure - usually done by aiming the camera at an area that is appropriately bright and pushing the shutter button down half way (which also locks the focus) then moving the camera back to its proper framing and taking the shot. This method can often allow you to get a good enough exposure for the areas of the photo being monitored even though some areas of the photo may still be too light or dark to make out. If this method still leaves important areas of the photograph too light or dark for use, you can take two or more photographs at different exposure settings in order to capture the full range of detail needed to compare with previous visits. This technique is known as bracketing and can be done by using the above method or by using the auto bracketing feature offered on some cameras (Figure G-2).

Most digital cameras have an ISO setting usually denoted as 100, 200, 400, 800, 1600, etc. Lower ISO settings generally make for much better image quality. But they also require the camera's shutter to remain open longer which can lead to blurry photos in dark or shaded conditions. Higher ISO settings make for much faster shutter speeds which reduce the chance for blurry photos. But they also create less detailed images due to sensor noise. Most daytime photos can be taken at the cameras lowest ISO setting. The photographer should always be careful to move the camera as little as possible when taking the picture to avoid blurry images regardless of the ISO setting used. In shaded, foggy, or extremely overcast conditions: the next lowest ISO setting that allows for none blurry images should be selected. Some cameras offer an image stabilization feature which helps to avoid image blur at slow shutter speeds. This feature (if available) should always be used regardless of conditions to ensure the sharpest images possible (Figure G-3).

Figure G-1 (*Next page*). Sequence of photos showing focus point and depth of field. (a) Focus point too close to camera; background is out of focus (f/2.8). (b) Focus point too far from camera; foreground is out of focus (f/2.8). (c) Focus point at ideal location, approximately one third of the way from the front of the frame. More of the photo is in focus, but the aperture setting of f/2.8 still does not allow the entire photo to be in focus. (d) Same focus point as (c), but the smaller aperture setting of f/8 allows the entire photo to be in focus.



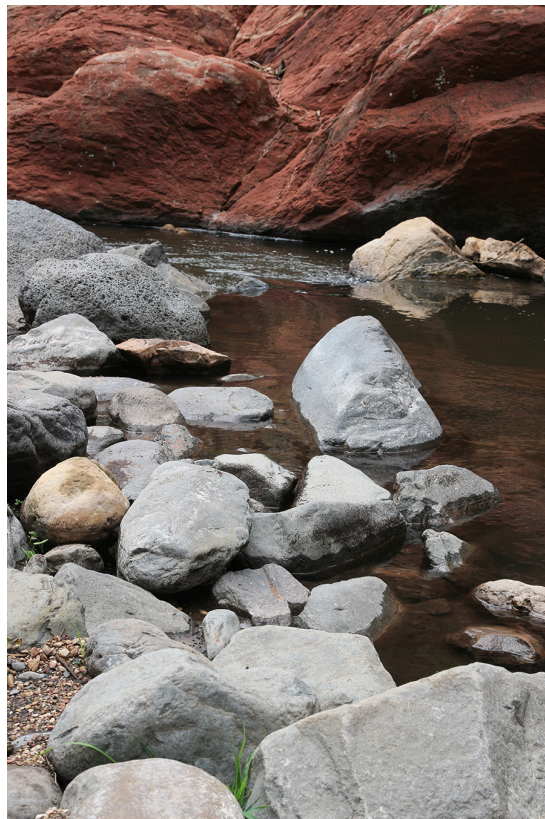
(a)



(b)



(c)



(d)



(a)



(b)



(c)

Figure G-2. Sequence of photos showing correct exposure and exposure bracketing technique. (a) Underexposed photo, (b) overexposed photo, and (c) properly exposed photo.



(a)



(b)



(c)



d)

Figure G-3. Sequence showing how shutter speed and ISO setting affect image quality. (a) The shutter speed for this photo was $1/3$ of a second due to the camera being set to the very small aperture of $f/32$. This speed is much too slow to keep movements of the photographer from blurring the photo. (b) With the aperture opened up to $f/8$ the photo can now be taken with a shutter speed of $1/80$ of a second, fast enough for a sharp photograph. (c) At ISO 6400 some loss of detail is apparent. (d) ISO 100 shows the fine details better.

Appendix H

List of Standard Operating Procedures for the *Water Quality Monitoring Protocol For Streams and Springs In The Southern Colorado Plateau Network*

This appendix lists each water quality monitoring standard operating procedures (SOP) and provides a clickable link to the document in IRMA.

Standard Operating Procedure #1: Preparing for the Field Season, Version SCPN_WATER_QUALITY_SOP01_20160901

Standard Operating Procedure #2: Hiring and Training Field Personnel, Version SCPN_WATER_QUALITY_SOP02_20160901

Standard Operating Procedure #3: Selecting and Documenting a Water Quality Monitoring Site, Version SCPN_WATER_QUALITY_SOP03_20160901

Standard Operating Procedure #4: Maintaining and Preparing Water Quality Monitoring Field Equipment, Version SCPN_WATER_QUALITY_SOP04_20160901

Standard Operating Procedure #5: Monitoring Core Water Quality Parameters, Version SCPN_WATER_QUALITY_SOP05_20160901

Standard Operating Procedure #6: Collecting Water Quality Samples, Version SCPN_WATER_QUALITY_SOP06_20160901

Standard Operating Procedure #7: Collecting and Processing Water Quality Samples for Fecal Indicator Bacteria, Version SCPN_WATER_QUALITY_SOP07_20160901

Standard Operating Procedure #8: Laboratory Analysis of Water Quality Samples, Version SCPN_WATER_QUALITY_SOP08_20160901

Standard Operating Procedure #9: Photopoint Monitoring, Version SCPN_WATER_QUALITY_SOP09_20160901

Standard Operating Procedure #10: Quality Assurance Project Plan for Water Quality Monitoring, Version SCPN_WATER_QUALITY_SOP10_20160901

Standard Operating Procedure #11: Shipping Samples to the Water Quality Laboratory, Version SCPN_WATER_QUALITY_SOP11_20160901

Standard Operating Procedure #12: Post Field Season Activities, Version SCPN_WATER_QUALITY_SOP12_20160901

Standard Operating Procedure #13: Project Workspace, Version SCPN_WATER_QUALITY_SOP13_20160901

Standard Operating Procedure #14: Data Entry, Version SCPN_WATER_QUALITY_SOP14_20160901

Standard Operating Procedure #15: Managing Time-Series Data, Version SCPN_WATER_QUALITY_SOP15_20160901

Standard Operating Procedure #16: Data Quality Review: Verification, Validation, and Certification, Version SCPN_WATER_QUALITY_SOP16_20160901

Standard Operating Procedure #17: Data Analysis and Reporting, Version SCPN_WATER_QUALITY_SOP17_20160901

Standard Operating Procedure #18: Revising the Protocol, Version SCPN_WATER_QUALITY_SOP18_20160901

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