



Streams Monitoring Protocol for the Sonoran Desert and Southern Plains Networks

Version 1.0

Natural Resource Report NPS/SODN/NRR—2018/1787



ON THE COVER

Using a pebble-counting frame at Montezuma Castle National Monument. NPS photo.

Streams Monitoring Protocol for the Sonoran Desert and Southern Plains Networks

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Natural Resource Report NPS/SODN/NRR—2018/1787

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Acronyms and Abbreviations

ADEQ	Arizona Department of Environmental Quality
BOD	biological oxygen demand
CDPHE	Colorado Department of Public Health and Environment
dbh	diameter at breast height
<i>E. coli</i>	<i>Escherichia coli</i>
EMAP	Environmental Monitoring and Assessment Program
EPA	Environmental Protection Agency
GRTS	Generalized Random Tessellation Stratified
HUC	hydrologic unit code
I&M	inventory and monitoring
KDHE	Kansas Department of Health and Environment
NAWQA	National Water-Quality Assessment
NELAP	National Environmental Laboratory Accreditation Program
NHP	national historical park
NHS	national historic site
NM	national monument
NMem	national memorial
NP	national park
NPS	National Park Service
NRA	national recreation area
OWRB	Oklahoma Water Resources Board
QA/QC	quality assurance/quality control
QAPP	quality assurance project plan
RMD	Rincon Mountain District
SODN	Sonoran Desert Network
SOPN	Southern Plains Network
SWNC	Southwest Network Collaboration
T&E	threatened and endangered
TCEQ	Texas Commission on Environmental Quality
TMD	Tucson Mountain District
USGS	U.S. Geological Survey

Species Named in this Document

American bullfrog	<i>Rana catesbeiana</i>
Apache trout	<i>Oncorhynchus apache</i>
Arizona sycamore	<i>Platanus wrightii</i>
bluegill sunfish	<i>Lepomis macrochirus</i>
Chiricahua fox squirrel	<i>Sciurus nayaritensis chiricahae</i>
Colorado pikeminnow	<i>Ptychocheilus lucius</i>
cottonwood	<i>Populus</i> spp.
desert willow	<i>Chilopsis linearis</i>
flathead chub	<i>Platygobio gracilis</i>
Fremont cottonwood	<i>Populus fremontii</i>
Gila topminnow	<i>Poeciliopsis occidentalis</i>
Goodding's willow	<i>Salix gooddingii</i>
green sunfish	<i>Lepomis cyanellus</i>
green sunfish × bluegill	<i>Lepomis cyanellus</i> × <i>macrochirus</i>
largemouth bass	<i>Micropterus salmoides</i>
lesser long-nosed bat	<i>Leptonycteris curasoae yerbabuenae</i>
loach minnow	<i>Tiaroga cobitis</i>
lowland leopard frog	<i>Rana yavapaiensis</i>
Mexican gray wolf	<i>Canis lupus baileyi</i>
Mexican spotted owl	<i>Strix occidentalis lucida</i>
Montezuma Well springsnail	<i>Pyrgulopsis montezumensis</i>
narrow-headed gartersnake	<i>Thamnophis rufipunctatus</i>
northern Mexican garter snake	<i>Thamnophis eques megalops</i>
quagga mussels	<i>Dreissena bugensis</i>
roundtail chub	<i>Gila robusta</i>
salt cedar	<i>Tamarisk</i> spp.
seepwillow	<i>Baccharis salicifolia</i>
southwestern willow flycatcher	<i>Empidonax traillii extimus</i>
spikedace	<i>Meda fulgida</i>
suckermouth minnow	<i>Phenacobius mirabilis</i>
western mosquitofish	<i>Gambusia affinis</i>
yellow-billed cuckoo	<i>Coccyzus americanus</i>
Yuma clapper rail	<i>Rallus longirostris yumanensis</i>

Abstract

Stream ecosystems are one of the most ecologically important, rare, and threatened natural resources in the American Southwest. This protocol outlines the justification, objectives, and procedures developed for long-term monitoring of aquatic and riparian systems in National Park Service units of the Sonoran Desert and Southern Plains networks. The protocol narrative describes the (1) background and rationale for monitoring streams, (2) program goals and objectives, (3) sampling design, (4) field methods, (5) data management, (6) analysis and reporting, (7) personnel requirements and training, (8) operational requirements, and (9) procedures for revising and reviewing the protocol. Detailed standard operating procedures that describe all aspects of the protocol are electronically available.

Streams monitoring provides information on several high-priority vital signs in Sonoran Desert and Southern Plains network parks, including water quantity, channel morphology, riparian vegetation, water quality, benthic macroinvertebrates, and stream wildlife. Because these parameters are closely interrelated, it is necessary to monitor them in conjunction with each other to achieve a complete picture of ecological function.

The overall goal of this stream monitoring is to ascertain broad-scale changes in aquatic and riparian system properties in the context of changes in other ecological drivers, stressors, and processes. In design, approach, and techniques, the monitoring described in this document closely follows the appropriate standard methods of the U.S. Geological Survey's National Water-Quality Assessment and Environmental Protection Agency's Environmental Monitoring and Assessment Program.

At least one permanent monitoring site is located in each park unit where streams are monitored. In parks with more than 10 kilometers (6.2 mi) of perennial, intermittent, or ephemeral stream, permanent monitoring sites were determined through a stratified, random, spatially balanced sampling design. At large parks, sites are sampled on a five-year panel design, in which one panel containing one-fifth of a park's total plots is sampled each year. At small parks, all sites are sampled within the same year, and not sampled again until the five-year interval is complete. Field methods, training, laboratory analysis, and data management procedures are detailed in standard operating procedures available at the National Park Service's Integrated Resource Management Applications portal.

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Protocol Narrative

Revision History Log

Previous version #	Revision date	Author	Change(s) made	Reason for change	New version #
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-

1 Background

This streams monitoring protocol consists of this protocol narrative and the following standard operating procedures (SOPs), available at <https://irma.nps.gov/DataStore/Reference/Profile/2256789>:

General

- SOP#1: Field Safety
- SOP#2: Staff Training
- SOP#3: Site Selection
- SOP#4: Cleaning and Decontamination of Field Equipment
- SOP#5: Data Management
- SOP#6: Revising the Protocol Narrative and SOPs

Module 1: Water Quantity

- SOP#7: Discharge

Module 2: Channel Morphology

- SOP#8: Surveying Cross-sections and Longitudinal Profile
- SOP#9: “Wolman” Type Pebble Count
- SOP#10: Mapping Wetted Width
- SOP#11: Segment Physical Characterization
- SOP#12: Using the Total Station

Module 3: Riparian Vegetation

- SOP#13: Before the Riparian Vegetation Field Season
- SOP#14: Riparian Vegetation Sampling
- SOP#15: Riparian Vegetation Daily Data Management
- SOP#16: After the Riparian Vegetation Field Season

Module 4: Water Quality

- SOP#17: Quarterly Sampling
- SOP#18: Continuous Water Quality Data
- SOP#19: Water Quality Core Parameters
- SOP#20: Water Quality Bottle Sampling
- SOP#21: Turbidity
- SOP#22: Sampling and Analysis of Fecal Indicator Bacteria
- SOP#23: Daily Data Management
- SOP#24: Continuous Water Quality Station Mount Installation

Module 5: Benthic Macroinvertebrates

- SOP#25: Macroinvertebrate Collection
- SOP#26: Habitat Characterization

Module 6: Fish and Other Wildlife

- SOP#27: Determining Status of Fish in Perennial Streams

The core mission of the National Park Service (NPS), as outlined in the agency’s 1916 Organic Act, is to protect and preserve the natural and cultural resources entrusted to it for the benefit of future generations. Responding to criticism that it lacked basic knowledge of natural resources within parks, the NPS initiated the Inventory and Monitoring (I&M) Program to detect long-term changes in biological resources (NPS 1992). Parks with significant natural resources were assigned to one of 32 monitoring networks, each based on ecological similarity and geographic proximity.

Each network was charged with developing a monitoring program capable of detecting long-term changes in physical and biological resources within its network parks. To detect those changes, networks identify and monitor a suite of “vital signs,” defined as a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. In cooperation with park staff, each network identified a set of vital signs appropriate for its network parks and developed a plan for long-term monitoring of those vital signs.

The monitoring plans for the Sonoran Desert Network (SODN) and Southern Plains Network (SOPN) identified vital signs representing a diverse range of natural resources, including air, water, climate, soils, plants, invertebrates, and vertebrates (NPS 2005; NPS 2008). Within each of these categories, a workgroup of between four and eight regional and national experts chose vital signs. Each workgroup evaluated high-priority re-

source issues and identified candidate vital signs on the basis of ecological significance, feasibility, and relevance to management (NPS 2005; NPS 2008).

At SODN and SOPN, workgroups for hydrology, vertebrates, invertebrates, plants, and soils all selected high-priority vital signs emphasizing the importance and feasibility of long-term monitoring of the condition of perennial streams and rivers from an integrated ecological perspective (Table 1-1, shown with the corresponding monitoring modules described below).

1.1 Protocol collaboration

This protocol is shared by the Sonoran Desert and Southern Plains networks via an established partnership, the Southwest Network Collaboration (SWNC). The SWNC also includes the NPS Chihuahuan Desert Network. Through this collaboration, the networks share knowledge, protocols, staff resources, and work duties. The goal of the SWNC is to improve monitoring effectiveness and efficiency across SWNC land-management units.

Table 1-1. Vital signs and monitoring modules for perennial streams in the Sonoran Desert and Southern Plains networks.

Streams protocol monitoring module	Vital sign(s)	
	Sonoran Desert Network	Southern Plains Network
Surface water quantity	Surface water dynamics	Water quantity (surface)
Stream channel morphology	Channel morphology	–
Riparian vegetation	Vegetation lifeform abundance	Riparian vegetation communities
	Vegetation community structure	Riparian vegetation communities
	Recruitment of dominant species	–
	Exotic plants status and trends	Exotic plants
Surface water quality	Water quality (core parameters)	Water quality (core parameters)
	Nutrient dynamics	–
	Pollutant metals (metal and metalloids)	–
	Microorganisms (biological condition)	–
	Carcinogens and toxins	–
	Suspended (and total) sediments	–
Benthic macroinvertebrates	Aquatic benthic macroinvertebrates	–
Fish and non-native animals	Fish community dynamics	–



Sonoran Desert Network Parks and Major Rivers

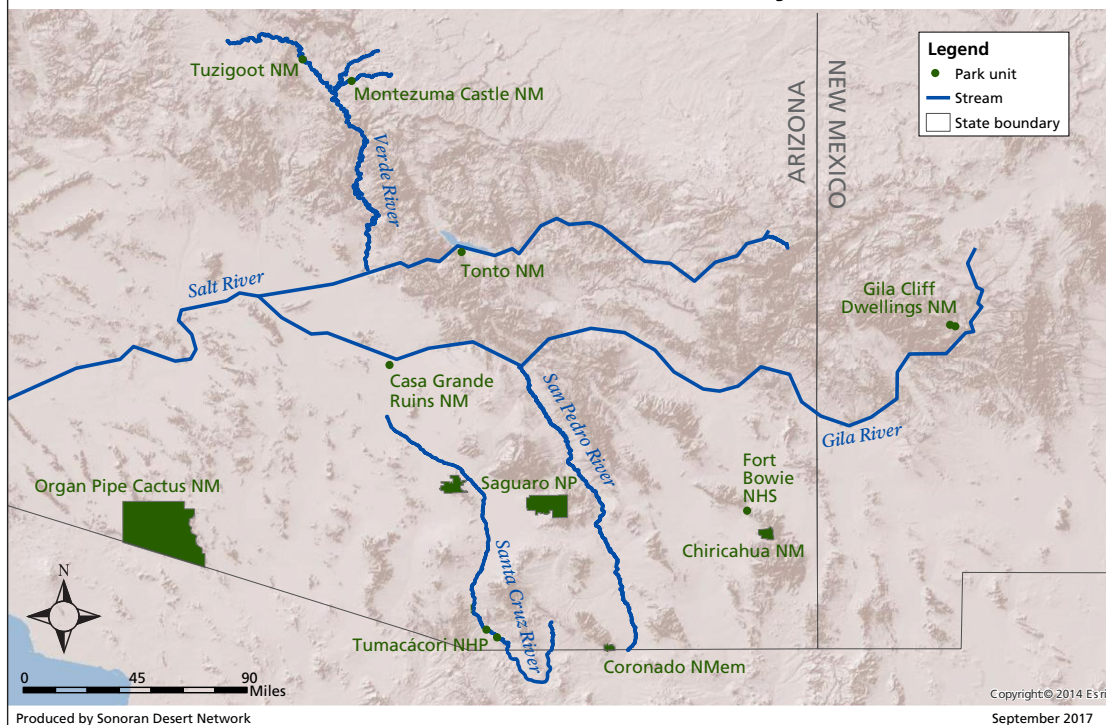


Figure 1-1. Park units and major rivers, Sonoran Desert Network.

The Sonoran Desert Network (Figure 1-1) includes 11 parks in southern Arizona and New Mexico: Casa Grande Ruins National Monument (NM), Chiricahua NM, Coronado (NMem), Fort Bowie National Historic Site (NHS), Gila Cliff Dwellings NM, Montezuma Castle NM, Organ Pipe Cactus NM, Saguaro National Park (NP), Tonto NM, Tumacácori National Historical Park (NHP), and Tuzigoot NM. These units range in size from 356 hectares (Tumacácori NHP) to 133,882 hectares (Organ Pipe Cactus NM). Collectively, they are representative of most ecological communities in the greater Sonoran Desert ecoregion (NPS 2005).

The Southern Plains Network (Figure 1-2) comprises 11 parks in Colorado, Kansas, Oklahoma, New Mexico, and Texas: Alibates Flint Quarries NM, Bent's Old Fort NHS, Capulin Volcano NM, Chickasaw National Recreation Area (NRA), Fort Larned NHS, Fort Union NM, Lake Meredith NRA, Lyndon B. Johnson NHP, Pecos NHP, Sand Creek Massacre NHS, and Washita Battlefield NHS. Many of these parks were es-

tablished for their cultural resources but all contain significant natural resources, as well (NPS 2008).

1.2 Why monitor streams?

Perennial streams are among the most critical and impacted natural resources of the American Southwest. The presence and extent of surface water has traditionally provided a focus for human habitation in the region, resulting in prehistoric and historic development coincident with reliable and abundant rivers, streams, wetlands, and springs. Further, more than 90% of all species in the ecoregion utilize aquatic ecosystems for some portion of their lifecycles (Phillips and Comus 2000), yet natural surface waters have decreased by an estimated 99% since the mid-19th century due to human demands for water (Tellman et al. 1997).

Perennial and intermittent rivers and streams ("streams") and ephemeral streams ("washes") are important resources in all SODN and SOPN parks. Portions of 10 major river sys-

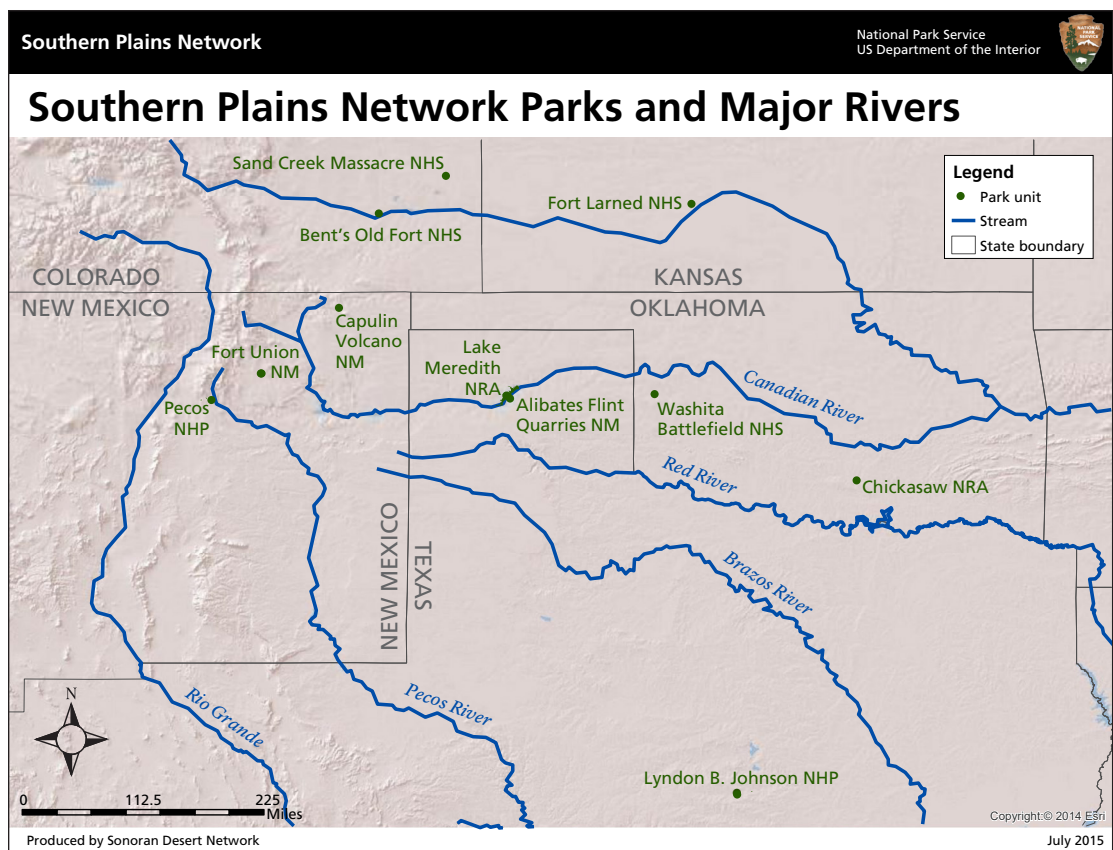


Figure 1-2. Park units and major rivers, Southern Plains Network.

tems (or their tributaries) are found in parks of the two networks. As human development in the American Southwest accelerates in the 21st century, these critical waters and the abiotic and biotic resources they support will grow in significance, as will the threats to their persistence. Riparian ecosystems are also popular recreation areas for park visitors, particularly in the seasonally dry parks of the American Southwest and Great Plains (Brauman et al. 2007). Therefore, effective protection of streams and their aquatic ecosystems is of paramount importance to managers of SODN and SOPN parks (NPS 2005; NPS 2008).

In the Sonoran Desert Network, perennial streams are located in four parks: Gila Cliff Dwellings NM, Montezuma Castle NM, Tumacácori NHP, and Tuzigoot NM. Intermittent streams and washes are found in nearly every park (except Casa Grande Ruins NM), and are important for movement and storage of water, and as habitat and travel corridors for wildlife. These streams face threats similar to those of perennial streams.

In the Southern Plains Network, perennial streams are found at six parks: Bent's Old Fort NHS, Chickasaw NRA, Lyndon B. Johnson NHP, Pecos NHP, Sand Creek Massacre NHS, and Washita Battlefield NHS. There are many kilometers of ephemeral streams across the SOPN parks; for example, Sand Creek, at Sand Creek Massacre NHS, is an ephemeral stream. Two parks, Fort Union NM and Capulin Volcano NM, have stream resources that do not warrant monitoring (NPS 2008). At Fort Union NM, the stream resources are adjacent to but not within the administrative boundary of the park. At Capulin Volcano NM, there are no streams or riparian areas.

1.3 Vital signs and monitoring modules

Streams are complex, dynamic systems that comprise interacting, interdependent biological and physical components. To support a comprehensive understanding of stream condition, we employ a holistic approach to monitoring the vital signs identified in

Table 1-1. This approach integrates key geomorphological, hydrological, and biological processes and indicators (NPS 2005; NPS 2008). The vital signs are organized into six modules in this protocol (see Table 1-1 and below). When investigated in combination, these vital signs will provide a powerful index of stream condition and function. The following sections describe the six modules and their associated vital signs.

1.3.1 Surface water quantity

Surface water quantity is the major ecological and physical process driver in stream and wash systems. It is the most important factor in understanding and managing aquatic and riparian ecosystems because the magnitude, timing, and duration of streamflow is the primary determinant of biophysical, chemical, and local landform characteristics in and along stream channels (Dunne and Leopold 1978). Determining status and monitoring trends in the amount of flow, hydrologic timing, baseflow, and flooding/drying that occurs will provide insight into larger regional processes (e.g., watershed, climate change) and allow for interpretation of results gathered from all other parts of this monitoring protocol.

1.3.2 Stream channel morphology

Stream-channel morphology is an important indicator of watershed condition. It integrates ecological and geomorphological processes, including soil erosion, nutrient cycling, discharge characteristics, and the occurrence and magnitude of disturbance events, as well as surface and groundwater quantity and quality (Fong et al. 2011). The primary ecological functions of stream channels are to dissipate the energy associated with overland flow and to transport sediment, water, and nutrients within and from the watershed (Dunne and Leopold 1978). Channel morphometrics respond to the frequency, magnitude, and duration of flow events, and are constantly adjusting to watershed conditions. The largest changes typically occur in response to seasonal flooding (Leopold et al. 1964). These rare, stochastic flow events, combined with changes in typical stream and wash flow, are of particular

importance in SODN and SOPN parks. Geomorphic characteristics of stream channels, such as channel shape, interact with biological components, most notably vegetation, and can be used to determine the type, extent, and configuration of riparian ecosystems (Hupp and Osterkamp 1996).

1.3.3 Riparian vegetation

Riparian vegetation (including xeroriparian vegetation and habitat in this protocol) represents a small percentage of the land cover in the American Southwest and southern plains, but provides important services, functions, and benefits. Riparian vegetation filters contaminants from water before they infiltrate groundwater drinking supplies, slows flood waters, reduces erosion potential along streambanks, increases groundwater recharge, and provides habitat for resident and migratory wildlife species (Brauman et al. 2007; Theobald et al. 2010; Tockner and Ward 1999).

Riparian vegetation communities vary depending on geomorphology and are sensitive to hydrologic change. Some trees, such as cottonwoods and willows, primarily rely on groundwater and are sensitive to change (Stromberg et al. 1996). Abrupt and permanent drops in groundwater of just one meter have killed mature cottonwoods and willows (Haney et al. 2008). In addition to plant/water relationships, the consequences of exotic plant invasions on aquatic and riparian vegetation are a primary focus of monitoring and management in parks of the American Southwest.

1.3.4 Surface water quality

Water quality is a critical measure of the chemical and biological properties of aquatic systems and has a major impact on human health and ecosystem function (UNESCO 2008). Aquatic ecosystems depend on the maintenance of particular water quality conditions in order to sustain life-supporting biochemical processes in plant and animal communities. Aquatic ecosystems are influenced by inputs of sediment, metals, nutrients, toxins, fire ash, sewage effluent, and biomass (Zaimes et al. 2007). Surface water

quality measures for SODN and SOPN parks consist of the five components described below.

1.3.4.1 Core water quality parameters

Core water quality parameters reflect the function of the physical and biological environment with which water interacts. SODN and SOPN core parameters—temperature, specific conductance, pH, dissolved oxygen, and proximate (in space and time) discharge rate—are easily measured and constitute a means of characterizing potential stressors to the health of aquatic systems. Monitoring for these parameters dovetails with that of the NPS servicewide water quality monitoring program, which requires each network to collect all of these parameters with any water quality monitoring effort (NPS 2002). These parameters also provide key insights into the other water quality parameters described below.

1.3.4.2 Primary nutrients

Nutrient levels in a stream result from a hierarchy of biotic and abiotic processes occurring in the watershed, riparian zone, hyporheic zone, parafluvial zone, and the stream itself (EPA 2000). Nitrogen and phosphorus are essential macronutrients for plant and animal life—but in excess, they can interact with the biological and physical environment to reduce the availability of high-quality aquatic habitat, altering the composition and species diversity of aquatic communities (EPA 2000). Measures of total nitrogen and total phosphorus indicate the potential for biological effects resulting from nutrient loading.

1.3.4.3 Biological condition

Assessment of biological condition (the term used in this protocol to include visual and olfactory qualitative assessments of water condition and two water quality metrics) complements the other water quality vital signs and provides insight to the overall biological condition of water. Two parameters are used to measure this vital sign: biological oxygen demand (BOD) and *Escherichia coli* (*E. coli*). BOD is a measure of how much oxygen is consumed by biological organisms to decompose organic matter in a body of water. *E. coli* is one of the main species of bacte-

ria living in the lower intestines of mammals. Its presence in water is an indication of fecal contamination. High levels of BOD and *E. coli* act as an index for organic pollution and may provide early warning of potential pollution risks to aquatic and terrestrial biota (EPA 2000).

1.3.4.4 Metals and metalloids

In high concentrations, metals can cause major disruption of aquatic ecosystems by lowering reproductive success, interfering with normal growth and development, and, in extreme cases, causing direct mortality of aquatic organisms. The relationship of metal toxicity to aquatic species is complex but well established (Langmuir et al. 2004). Surface waters in SODN and SOPN parks are exposed to pollutant metals through both point and non-point sources, including mine drainage, roadways, aerosolized particles dispersed through industrial processes, agricultural runoff, and the release of metals naturally occurring in near-surface rock strata and sediments (Sprouse et al. 2004). Most of these contaminants bioaccumulate in aquatic food webs and may pose long-term threats to all trophic levels of the aquatic environment (EPA 2005).

1.3.4.5 General water quality and inorganic metrics

This group consists of general water quality metrics that are important both by themselves (e.g., sulfate) and for interpreting other parameters (e.g., alkalinity). Alkalinity characterizes the ability of a water body to buffer changes in pH. Naturally occurring ions, such as carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), and hydroxide (OH^-), buffer streams from sudden changes in pH due to the addition of acid. Alkalinity of a stream is influenced by surrounding geology and soils and by the presence and chemical composition of effluent and agricultural and industrial runoff. Alkalinity benefits wildlife in two ways: first, by protecting fish and other organisms from sudden changes in pH. Second, under the right conditions, carbonate and bicarbonate ions facilitate the precipitation of metals from solution, reducing the exposure of aquatic biota to high concentrations of dissolved metals.

An additional suite of inorganic analytes is of interest: chloride, fluoride, and sulfate. Fluoride and chloride indicate and inform biogeochemical processes. High concentrations of sulfate can indicate impact of industrial and agriculture activity from runoff or deposition (Weiner 2008).

1.3.5 Benthic macroinvertebrates

Benthic macroinvertebrates (macroinvertebrates) are an important biological component in streams. They contribute to nutrient cycling and organic decomposition and are important prey for fish and other aquatic vertebrates. They also can be a useful indicator of stream function and water quality. Living on the bottom substrates or the sediment in streams, macroinvertebrate species—and, to a degree, taxa—respond differently to a variety of aquatic stressors over varied timescales. Thus, the ecological consequences of stress and contamination on stream systems can be assessed by analyzing species composition and distributions for the aquatic macroinvertebrate community (Stoddard et al. 2005).

Macroinvertebrates can therefore provide a powerful and relatively inexpensive biological indicator of water quality and local conditions (Karr et al. 1986; Rosenberg and Resh 1993). They have been used extensively to assess stream condition because they are sensitive to pollutants and have high species richness. They also live in contact with sediment where pollutants tend to concentrate, and taxa and lifeform response to pollutants are relatively well established (Karr et al. 1986; Reice and Wohlenberg 1993). Because they are relatively long-lived, macroinvertebrates integrate exposure to water condition over substantial time scales. This protocol uses the Arizona index of biological integrity (IBI) as the major metric, using state-defined indices to assess if the index reach is meeting total maximum daily load for macroinvertebrates.

1.3.6 Fish and other wildlife

Fish are the highest-level organisms in this streams monitoring project. Fish assemblages can serve as effective indicators of ecological conditions for several reasons. Fish are long-

lived and mobile, forage at different trophic levels, integrate ecosystem conditions at both higher and lower trophic levels, and are reasonably easy to identify in the field. Fish also respond to higher-order processes captured in the other elements—particularly, stream channel morphology, riparian vegetation, and water quantity (for physical habitat); water quality (for health), and macroinvertebrates (for food).

Non-native (exotic) animals pose a significant risk to the aquatic wildlife in SODN and SOPN streams. Crayfish are an important non-native predator of fish and one of the most serious threats to native aquatic biota because they effectively compete with aquatic herbivores, prey on aquatic invertebrates and vertebrates, disrupt normal nutrient cycling, and decrease aquatic macroinvertebrate diversity (Creed 1994). In addition, their extensive burrowing leads to bank erosion, increased turbidity, and siltation. Other non-native aquatic animals of concern include American bullfrogs (*Rana catesbeiana*), non-native fish, and quagga mussels (*Dreissena bugensis*).

Nearly all fish species found in SODN parks are either of special concern (e.g., Gila topminnow; *Poeciliopsis occidentalis*) or non-native and invasive (e.g., green sunfish; *Lepomis cyanellus*) (NPS 2015). The presence of rare or invasive fish species is of interest to park managers, and may result in specific management actions.

In addition to being important focal resources for park management, monitoring fish populations in conjunction with other key attributes of aquatic ecosystems can provide a powerful assessment of the ecological integrity (i.e., the ability of an ecosystem to support and maintain ecological processes and biological diversity) of surface waters (Barbour et al. 1999; Moulton et al. 2002).

1.4 General monitoring approach

Our approach to monitoring SODN and SOPN streams builds on similar protocols that have been extensively tested and applied by various state and federal agencies and academic researchers. This protocol in-

corporate widely accepted methods and designs developed by the U.S. Geological Survey (USGS) for the measurement of surface water quantity (Smith et al. 2010; Turnipseed and Sauer 2010) and riparian habitat assessment (see Gilliom et al. 2014 for an overview); and by the Environmental Protection Agency (EPA) National Rivers and Streams Assessment (EPA 2013) and USGS for water quality and benthic macroinvertebrates (USGS various dates).

We use the methods and standards for collecting and calculating biological integrity indices and associated habitat assessments published and used by the state in which each park is located as the basis for data collection and interpretation (Table 1-2). The SODN and SOPN streams protocol only deviates from these national and state-level programs in (1) sampling frame (individual park vs. state, regional, or national scales), and (2) scope; in some instances, we have added additional, park-scale monitoring objectives that address specific park resource management issues.

1.5 Streams, washes, and associated stressors in SODN units

The lengths of the perennial, intermittent, and ephemeral streams for this section are derived from the USGS National Hydrography Dataset (2014). A summary of the types and lengths can be found in Appendix A. All parks with perennial, intermittent, and ephemeral streams are described, regardless of whether the network currently monitors streams in those units. Ecoregion boundaries are derived from The Nature Conservancy (2008).

1.5.1 Chiricahua National Monument

- **Size:** 4,850 hectares (11,985 ac)
- **Elevation:** 1,554–2,385 meters (5,100–7,824 ft)
- **Waterways:** ~76 kilometers (~47 mi) of ephemeral and intermittent streams.

Chiricahua National Monument is located on the western side of Chiricahua Moun-

Table 1-2. Source for water quality standards and sampling procedures by state.

State	SODN	SOPN	Standards and sampling procedures
Arizona	X	–	Arizona Department of Environmental Quality (ADEQ). 2015. Standard operating procedures for surface water quality sampling. Phoenix, AZ. 333 pp. + Appendices A–C.
Colorado	–	X	Colorado Department of Public Health and Environment (CDPHE). 2010. Aquatic life use attainment, methodology to determine use attainment for rivers and streams, policy statement 10-1. Water Quality Control Commission. 14 pp. + Appendices A–E.
Kansas	–	X	Kansas Department of Health and Environment (KDHE). 2004. Article 16: Unofficial Kansas water quality standards and supporting documents (K.A.R. 28-16-28b through 28-16-28g) Division of Environment, Bureau of Water. Topeka, KS. 12 pp. + supporting documents.
New Mexico	X	X	Jacobi G. Z., and others. 2006. Benthic macroinvertebrate stream condition indices for New Mexico wadeable streams. New Mexico Environment Department. Santa Fe, NM. 29 pp. + Appendix E, H.
Oklahoma	–	X	Standards: Oklahoma Water Resources Board (OWRB). 2013. Oklahoma's Water Quality Standards. Water Quality Division. Title 785, Chapter 45. 33 pp. +appendices. Sampling procedures: OWRB. 2013. Standard Operating Procedure for the Collection of Water Quality Samples in Streams DRAFT. Water Quality Programs Division. Pages 1–21.
Texas	–	X	Standards: Texas Commission on Environmental Quality (TCEQ). 2013. Texas Surface Water Quality Standards. Chapter 307.1-307.10. Pages 1–165. Sampling procedures: TCEQ. 2012. Surface Water Quality Monitoring Procedures, Volume 1: Physical and Chemical Monitoring Methods. Water Quality Planning Division, Monitoring and Assessment Section. RG-415. P171 + appendices A–D.

tains, in southeastern Arizona. Though it is part of the Sonoran Desert Network, Chiricahua NM lies east of the Sonoran Desert, in a region called the Apache Highlands. The Apache Highlands are characterized by mountain “sky islands” separated by grassland and desert scrub “seas” (Marshall et al. 2004). Here, relatively cool and moist mountain summits contain lifezones more characteristic of Canada than those of the valley bottoms below. The monument sits in between the Rocky Mountain and Sierra Madre biomes (NPS 2005).

The two main streams of Chiricahua NM are Bonita Creek (an intermittent stream) and its tributary, Rhyolite Creek (an ephemeral stream). Bonita Creek flows out of the park and eventually into the Willcox Playa, in the Sulphur Valley to the west. The land to the north, east, and south of the park is under the jurisdiction of the U.S. Forest Service. The land to the west is privately held and used for residential and ranching operations.

The monument’s streams and adjoining riparian areas provide habitat for wildlife, including the rare Chiricahua fox squirrel (*Sciurus nayaritensis chiricahae*), Mexican spotted owl (*Strix occidentalis lucida*), and lesser long-nosed bat (*Leptonycteris curasoae yerbabuenae*).

Stressors to monument streams include the impact of climate change on levels of precipitation and evapotranspiration, and the impact of large wildfires. In 2011, the Horseshoe II Fire burned a majority of the monument. Subsequent flooding events have resulted in changes in sedimentation and erosion at many wash and stream sites in this park, altering some riparian habitat on Bonita and Rhyolite creeks. The flow events have also impacted the water-supply infrastructure at the park, increasing the possibility of contamination of park wells (Sprouse et al. 2002).

Other threats include metal and inorganic leachate from the inactive King of Lead mine, located adjacent to the park, outside the boundary, at the top of the Bonita Creek drainage. It is possible that drainage from tailing piles and at least one adit may impact

aquatic resources downstream, including resources in the park. The mine is privately owned, and although unlikely, may become active in the future (Sprouse et al. 2002).

1.5.2 Coronado National Memorial

- **Size:** 1,922 hectares (4,750 ac)
- **Elevation:** 1,433–2,347 meters (4,701–7,700 ft),
- **Waterways:** ~52 kilometers (~32 mi) of washes, including Montezuma Wash, the major ephemeral stream draining most of the park.

Coronado National Memorial is located in southeastern Arizona, at the southern end of the Huachuca Mountains, along the international border with Mexico. This park lies near the center of the Apache Highlands ecoregion and preserves a rich biological and geological diversity. There are several perennial and intermittent springs at the memorial, located mostly in the beds of ephemeral streams.

The main stressors on the park’s stream and riparian areas are the indirect impact of climate change on precipitation patterns, temperature, and vegetation (Munson et al. 2012); the subsequent impacts of wildfires; the impact of several decommissioned mines; and the degradation of riparian habitat by smugglers and others crossing the border illegally (Sprouse et al. 2002).

The impact of extensive mining (ongoing in Montezuma Canyon and other parts of the park since the 17th century) on the park’s washes is unknown. There are at least 63 known mine sites. Several (such as the mine at the Blue Waterfall springs complex) impact water quality, with exceedances for beryllium, cadmium, copper, silver, zinc and selenium. Entrainment of compounds in the water that flows across mine tailings and into the ephemeral streams is likely. The extent and impact on human health and wildlife at this site are unknown, but other studies conducted in the region (Towne and Stephenson 2003; Norman et al. 2008) have indicated exceedances of national and federal standards.

1.5.3 Fort Bowie National Historic Site

- **Size:** 405 hectares (1,000 ac)
- **Elevation:** 1,417–1,600 meters (4,649–5,249 ft)
- **Waterways:** ~15.3 kilometers (9.5 mi) of ephemeral streams, which drain into the Sulphur Valley to the west and the San Simon Valley to the east.

Fort Bowie National Historic Site is located in southeastern Arizona, in the Apache Highlands ecoregion. The park occupies most of Apache Pass, which is a saddle between the Dos Cabezas Mountains to the north and the Chiricahua Mountains to the south.

The park's largest drainage is Siphon Canyon. The Siphon Canyon system includes the largest perennial spring in the park, Apache Spring. The constant presence of water has allowed for a significant xeroriparian system to develop in this part of Siphon Canyon.*

The main stressors on the wash and adjoining riparian areas include the indirect effects of climate change on precipitation patterns, temperature, and vegetation (Munson et al. 2012), as well as patterns of erosion and sedimentation. Impacts on stream morphology and water quality may be caused by illegal immigration and drug smuggling (Weiner 2008) but the extent of these impacts is unknown. There are also old mine locations near the park that may impact water quality during intense flow events. However, most mining and ranching operations were located downstream from the park, and pose a minimal threat (Sprouse et al. 2002).

1.5.4 Gila Cliff Dwellings National Monument

- **Size:** 216 hectares (533 ac)
- **Elevation:** 1,829 meters (6,000 ft)
- **Waterways:** A two-kilometer (1.2-mi) segment of the West Fork of the Gila River and 3.4 kilometers (2.1 mi) of ephemeral streams.

Gila Cliff Dwellings National Monument is located near the headwaters of the Gila

River in southwestern New Mexico. Though it is part of the Sonoran Desert Network, Gila Cliff Dwellings NM lies east of the Sonoran Desert, in the Arizona–New Mexico Mountains ecoregion. Its location at a biogeographic transition point between the Sonoran and Chihuahuan deserts on the east and west, and the Rocky Mountains and Sierra Madre to the north and south, is reflected in the park's diverse flora and fauna. This is one of SODN's smaller parks.

The West Fork of the Gila River supports lush riparian gallery forests dominated by Fremont's cottonwood (*Populus fremontii*) and Goodding's willow (*Salix gooddingii*). Approximately 70% of annual precipitation falls during summer monsoon events, although winter precipitation (often as rain-on-snow events) is particularly important for the occurrence of bankfull and flooding (Sprouse et al. 2002).

Because Gila Cliff Dwellings NM is surrounded by the Gila Wilderness (managed by the Gila National Forest), direct anthropogenic threats to stream function (physical chemical and biological processes occurring in stream ecosystems) within the monument are relatively minor. Stressors include direct and indirect anthropomorphic impacts, such as climate change, sedimentation and vegetation loss following recent large fires in and around the monument, and localized *E. coli* and associated human and pack-animal waste issues. Other issues include the effects of non-native animals, such as crayfish, American bullfrog, and five species of non-native fish.

Loss of quality water resources has the potential to impact nine federally threatened and endangered (T&E)/candidate species: Apache trout (*Oncorhynchus apache*), loach minnow (*Tiaroga cobitis*), Mexican gray wolf (*Canis lupus baileyi*), Mexican spotted owl, narrow-headed gartersnake (*Thamnophis rufipunctatus*), roundtail chub (*Gila robusta*), spikedace (*Meda fulgida*), and yellow-billed cuckoo (*Coccyzus americanus*) (NPS 2005). Seven of these species (all but Mexican gray wolf and Mexican spotted owl) are aquatic or riparian-obligate species.

*Springs (such as Apache Spring), seeps, and tinajas are monitored under the SODN springs protocol (McIntyre et al. in prep).

1.5.5 Montezuma Castle National Monument

- **Size:** 334 hectares (826 ac)
- **Elevation:** 963–1,103 meters (3,159–3,617 ft)
- **Waterways:** Wet Beaver Creek (1.2 km in Well unit) flows into Beaver Creek (4.6 km in Castle unit) upstream of the Montezuma Castle unit.

Montezuma Castle National Monument is located in central Arizona, approximately midway between Phoenix and Flagstaff. The park is part of the Apache Highlands ecoregion. It consists of two units, with the Castle unit alongside Beaver Creek and the Well unit alongside Wet Beaver Creek. Both Beaver Creek and Wet Beaver Creek are tributaries of the Verde River. Their watershed areas are approximately 322 and 692 km² (124 and 267 mi²), respectively (Sprouse et al. 2002). The gallery forests associated with both units consist largely of cottonwood (*Populus* spp.), seepwillow (*Baccharis salicifolia*), desert willow (*Chilopsis linearis*), and Arizona sycamore (*Platanus wrightii*). Both units also contain areas of velvet mesquite bosque (riparian woodland).

Because both Beaver Creek and Wet Beaver Creek originate on the Mogollon Rim, precipitation patterns and watershed conditions at much higher elevations drive streamflow and conditions within this desert park. Precipitation is essentially bimodal, with summer monsoons and winter snowmelt determining the magnitude and timing of streamflow and water temperature. Although the headwaters are largely wilderness areas, managed by the U.S. Forest Service, urban and exurban development and water extraction around both park units have proximate effects on conditions within the park.

Stressors at Montezuma Castle NM include increased sedimentation, nutrient loading, *E. coli* contamination, pollution from urban and agricultural runoff, decreased streamflow due to groundwater extraction and surface-water diversions, and the presence of non-native plants and animals, including crayfish, American bullfrog, and five species of non-native fish (Schmidt et al. 2006). Trespass livestock are also an occasional problem

within the riparian area, where they graze native plants, deposit nutrients and *E. coli*, and may spread the seed of exotic grasses.

Loss of quality water resources has the potential to impact four T&E/candidate species at Montezuma Castle NM: southwestern willow flycatcher (*Empidonax traillii extimus*), yellow-billed cuckoo, Montezuma Well springsnail (*Pyrgulopsis montezumensis*), and roundtail chub.

1.5.6 Organ Pipe Cactus National Monument

- **Size:** 133,825 hectares (330,689 ac)
- **Elevation:** 305–1,463 meters (1,000–4,800 ft)
- **Waterways:** Over 1,900 kilometers (1,180 mi) of ephemeral streams, ranging from steep, rocky washes at higher elevations to wide, sandy washes dominated by xeroriparian habitat in the basins (USGS 2014).

Organ Pipe Cactus National Monument is the largest park in the Sonoran Desert Network. It is located directly on the international border with Mexico, and sits between the Tohono O’odham Indian Reservation to the east and the Cabeza Prieta National Wildlife Refuge to the west. The Bureau of Land Management manages most of the land north of the park. It is part of the Sonoran Desert Basin and Range Province system, with the Ajo Mountains, at 1,463 meters (4,800 ft), on the eastern side of the park (NPS 2005).

The monument’s extensive washes provide corridors for the movement of water, organic material, wildlife, and humans (Norton et al. 2007). A small number of perennial and seasonal water at widely scattered springs and tinajas persist.

Threats to park washes include the indirect effects of climate change on precipitation patterns, temperature, and vegetation (Munson et al. 2012) and subsequent changes in vegetation, erosion, and sedimentation patterns. Smugglers and others crossing the border illegally often pollute washes with debris and human waste. Erosion can be increased by illegal foot traffic (Webb et al. 2013) as well

as operations conducted by the Department of Homeland Security to counter illegal activity. Driving trucks and off-road vehicles across the desert, and building fences that impair streamflow, can have negative effects on wash ecology and human health (Belnap et al. 2008).

1.5.7 Saguaro National Park

- **Size:** Rincon Mountain District, 27,233 hectares (67,293 ac); Tucson Mountain District, 9,726 hectares (24,034 ac)
- **Elevation:** Rincon Mountain District, 814–2,641 meters (2,670–8,665 ft); Tucson Mountain District, 664–804 meters (2,180–4,687 ft)
- **Waterways:** The Rincon Mountain District (RMD) has extensive washes and intermittent streams (532 km/330 mi), with many perennial and intermittent springs and tinajas (USGS 2014). The Tucson Mountain District (TMD) is drier and lower, with less-persistent waters but with an extensive systems of washes (169.6 km/105 mi).

Saguaro National Park comprises two districts surrounding the Tucson metropolitan area: the Rincon Mountain District (RMD) and the Tucson Mountain District (TMD). The park is part of the Sonoran Desert and Apache Highlands ecoregions. As elevation increases, it spans several biomes, including desertscrub, Chihuahuan grassland and pine-oak, and mixed conifer montane woodland.

Threats to Saguaro NP streams include the indirect effects of climate change on precipitation patterns, temperature, and vegetation (Munson et al. 2012) and subsequent changes in vegetation, erosion, and sedimentation patterns. Wildfire also has had a significant impact on washes in the RMD, resulting in erosion and sedimentation that have extirpated aquatic species (e.g., lowland leopard frog; *Rana yavapaiensis*) from the affected drainages (Parker 2006). Other threats to the RMD include groundwater withdrawal that can negatively impact the duration of flow in Rincon Creek, an intermittent stream. There are abandoned mines in the TMD, and suspension of mine tailings is a possible threat to

park resources and adjoining property owners (Sprouse et al. 2004).

1.5.8 Tonto National Monument

- **Size:** 453 hectares (1,119 ac)
- **Elevation:** 700–1,200 meters (2,296–3,937 ft)
- **Waterways:** 11.8 kilometers (7 mi) of washes and seasonally intermittent stream reaches (USGS 2014).

Tonto National Monument is located in east-central Arizona, in Gila County. The park is located within the Tonto National Forest and lies in the Tonto Basin, an inclusion of the Sonoran Desert nestled against the Mogollon Rim along the Salt River in central Arizona. The sharp escarpment of the Mogollon Rim separates the Sonoran Desert ecoregion from the Apache Highlands ecoregion (Gori and Enquist 2003), and the proximity of the monument to this major transition is reflected in its diverse flora and fauna (Albrecht et al. 2007).

Threats to park streams include indirect effects of climate change on precipitation patterns, temperature, and vegetation (Munson et al. 2012) and subsequent changes in vegetation, erosion, and sedimentation patterns. Up-gradient management activity by the U.S. Forest Service, including cattle grazing, off-road vehicle use, application of herbicides and fire retardant, and prescribed fire could potentially alter the stream channel, water quality, vegetation, and wildlife habitat (NPS 2005).

1.5.9 Tumacácori National Historical Park

- **Size:** 146 hectares (360 ac)
- **Elevation:** 994–1,097 meters (3,261–3,599 ft)
- **Waterways:** About 2.7 km (1.6 mi) of the Santa Cruz River, which drains more than 1,770 km² (683 mi²), flows perennially through the Mission unit of Tumacácori NHP.

From its headwaters in the San Rafael Valley, the Santa Cruz River flows south into Mexico, where it makes a 40-kilometer (25-mi)

U-turn and then flows north back into the United States, eventually reaching Tumacácori NHP in southern Arizona, between the cities of Tucson and Nogales. The park's three units are found in the Sonoran Desert ecoregion.

Historically, Santa Cruz River streamflows were maintained by surface runoff and groundwater discharge. The increasing use of groundwater pumps in the first half of the 20th century resulted in a dewatering of the river and reduction of the riparian corridor along its length. Beginning in 1972, flow was restored to the river by the introduction of discharge to the stream channel from the Nogales International Wastewater Treatment Plant in Rio Rico, Arizona. The plant discharges roughly 13 million gallons of effluent a day into the Santa Cruz River, with two-thirds of the wastewater generated in Mexico (IBWC 2009). Significant upgrades were made to the Nogales Wastewater Treatment Plant in spring 2009, improving subsequent water quality by drastically reducing the nutrient load (Gwilliam et al. 2016).

Threats to water quality and general ecosystem function in the Santa Cruz River include a variety of microbial pathogens, including *E. coli*, *giardia*, and *cryptosporidia*. Varied streamflow due to complex interactions between wastewater management (including a new Sonoran facility that exports effluent from the watershed; Prichard and Scott 2013) and groundwater extraction is a particular concern for aquatic and riparian systems within the park, as are the effects of invasive non-native animals, such as crayfish, American bullfrog, and four species of exotic fish, plus one hybrid: western mosquitofish (*Gambusia affinis*), green sunfish, green sunfish × bluegill (*Lepomis cyanellus* × *macrochirus*), bluegill sunfish (*Lepomis macrochirus*), and largemouth bass (*Micropterus salmoides*) (Powell et al. 2005).

Three T&E/candidate species may be impacted by degraded water quality: Gila topminnow, southwestern willow flycatcher, and yellow-billed cuckoo (Powell et al. 2005).

1.5.10 Tuzigoot National Monument

- **Size:** 338 hectares (834 ac)

- **Elevation:** 1,024–1,036 meters (3,360–3,400 ft)
- **Waterways:** The Verde River travels through the park for a distance of about 1.6 kilometers (1 mi). Other perennial (e.g., the creek that drains Tavasci Marsh) ephemeral, and intermittent streams total 5.5 kilometers.

Tuzigoot National Monument lies within the Verde Valley and the middle Verde River watershed of north-central Arizona. This park is part of the Apache Highlands ecoregion. The watershed area that contributes to the Verde River at the park is approximately 9,234 km² (3,565 mi²). While the channel of the Verde River runs through Tuzigoot NM, much of the water at baseflow is diverted out of the park and into the Cottonwood Ditch. The riparian vegetation associated with the park consists largely of tree species, primarily cottonwood (*Populus* spp.), seepwillow (*Baccharis salicifolia*), desert willow (*Chilopsis linearis*), and Arizona sycamore (*Platanus wrightii*).

A tributary of the Salt River, the Verde River flows intermittently through the Big Chino Valley. Perennial flow begins just upstream of Granite Creek, near Pauldon, Arizona. The stretch of the river between the headwaters and Sycamore Canyon, called the upper Verde River, is fairly undeveloped. Between Sycamore Canyon and Camp Verde, the middle Verde River is bordered by development and agriculture (Haney et al. 2008). Streamflow in the middle Verde River (including the portion of the river that flows through Tuzigoot NM) is sustained by surface runoff, baseflow from the upper Verde River, groundwater discharge from the Verde Basin aquifer, and contributions from the major tributaries within the middle Verde River watershed (Haney et al. 2008). Outflow from Tavasci Marsh (located within the park) adds to streamflow in the Verde River along the southern extent of the park.

Streamflow in the Verde River at Tuzigoot NM is heavily modified by surface-water diversions (such as the Cottonwood Ditch), groundwater pumping, upstream floodplain development, and flood control infrastructure (Haney et al. 2008). Nearby groundwa-

ter extraction also reduces the magnitude of baseflow by removing subsurface water, some of which would otherwise discharge to the river (Filippone and Leake 2005).

Threats to water quality at Tuzigoot NM include high nutrient levels, low dissolved oxygen and pH, and potentially heavy metal pollution from Peck's Lake, an artificial pond associated with nearby copper-mining activities that drains into the Verde River via Tavas-ci Marsh. Invasive non-native animals that threaten aquatic and riparian resources associated with the Verde River within the park include crayfish, American bullfrog, and 11 species of non-native fish. Trespass livestock are also an occasional problem within the riparian area, where they graze native plants, deposit nutrients and *E. coli*, and may spread the seed of exotic grasses.

Seven T&E/candidate species may be affected by degraded water quality and quantity at Tuzigoot NM: Colorado pikeminnow (*Ptychocheilus lucius*), Gila topminnow, loach minnow, northern Mexican garter snake (*Thamnophis eques megalops*), spikedace, yellow-billed cuckoo, and Yuma clapper rail (*Rallus longirostris yumanensis*; Schmidt et al. 2005).

1.6 Streams and associated stressors in SOPN units

The lengths of the perennial, intermittent, and ephemeral streams presented in this section were derived from the USGS National Hydrography Dataset (2014). A summary of the types and lengths can be found in Appendix A. All parks with perennial, intermittent and ephemeral streams are described, regardless of whether the network currently monitors streams in those units.

1.6.1 Bent's Old Fort National Historic Site

- **Size:** 323 hectares (799 ac)
- **Elevation:** 1,230 meters (4,035 ft)
- **Waterways:** The park contains approximately three kilometers (1.9 miles) of the Arkansas River, several associated wetlands and ponds, and approximately five kilometers (3.1 miles) of diversion

ditches, canals, and other man-made waterways.

Bent's Old Fort National Historic Site is located in southeastern Colorado, within the Great Plains-Palouse Steppe and the short-grass prairie ecoregion (Bailey 1995). Maintaining the integrity of the riparian habitats, particularly cottonwood/willow communities, is a primary concern for park managers.

Threats to riparian resources at Bent's Old Fort NHS include major upstream diversions and groundwater extraction for agriculture that affect streamflow through the park. Over the past century, these activities have led to a change in river morphology—decreasing particle size, sinuosity, and slope and increasing the mean stage by 0.6 meters (2 ft). Additional threats come from potential contamination by fertilizers and pesticides in agricultural runoff, and nutrients and increases in pathogens associated with effluent discharge (Vana-Miller et al. 2010). The park conducted extensive control and restoration for salt cedar (*Tamarisk* spp.) in the early 21st century and seeks to prevent that species from returning to the park.

Two rare fish are found at the park: flathead chub (*Platygobio gracilis*) and suckermouth minnow (*Phenacobius mirabilis*). The continued existence of these fish is threatened by non-native fish and poor habitat and water quality (Vana-Miller et al. 2010).

The water quality at Bent's Old Fort NHS is generally turbid, with high concentrations of selenium and salt. These high salt concentrations are the result of natural conditions (the base material in the watershed is a marine shale), heavy agricultural use, and infiltration from canals. The segment of the Arkansas River at Bent's Old Fort is a 303(d)-listed water for selenium and has high levels of *E. coli*, salinity, and sulfates (Vana-Miller et al. 2010).

1.6.2 Chickasaw National Recreation Area

- **Size:** 4,002 hectares (9,889 ac)
- **Elevation:** 304 meters (1,000 ft)
- **Waterways:** The two largest bodies of water at Chickasaw NRA are the Lake

of the Arbuckles and Veterans Lake. Antelope and Buffalo springs have an approximate combined flow of as much as 3–5 million gallons per day. However, due to occasional severe drought conditions, the bed of Travertine Creek, which is fed by the springs, is sometimes dry. Rock Creek is the main perennial stream flowing through Chickasaw NRA, draining the city of Sulphur and most of the park.

Chickasaw National Recreation Area occupies the Arbuckle Mountains geographic region and the Red River drainage basin of south-central Oklahoma. The park was established in large part to protect the unique freshwater and mineral springs in this area. These sites are of particular importance to the Chickasaw and Choctaw tribal nations (Wilke et al. 1998).

Lake of the Arbuckles, at approximately 951 hectares (2,350 ac), is heavily used for recreation in the summer months. Swimming, boating, and fishing (mostly for small and largemouth bass) generally occur from May until September.

The most significant threats facing park waters include erosion along lakes and streams, exotic plant invasions, visitor effects on natural resources, water mining, and adjacent land-use practices. Chickasaw NRA's streams, springs, and wells overlay the Arbuckle-Simpson aquifer, a sole-source aquifer for the southern central Oklahoma region. Growing use of the aquifer for drinking-water supply and increasing numbers of wells are causing concern that a lowered water table could negatively affect the park's springs. Strip mines in the area of Sulphur, Oklahoma, located in the aquifer's recharge area, could present an added problem to groundwater quality in the future (NPS 2008).

Many of the park's streams and lakes are highly influenced by the surrounding urban interface and increasing recreational activities. Rock Creek is of particular concern, as it both runs through a large campground in the park and is situated downstream from the city of Sulphur's wastewater treatment plant. Another emerging concern for park staff is

the rise in boating use at Lake of the Arbuckles, and the possibility of hydrocarbon contamination (NPS 2008).

Oklahoma's 2002 watershed assessment lists Lake of the Arbuckles as in good condition and Rock Creek as an impaired waterway. Other water bodies have yet to be assessed by the state. The most commonly exceeded criteria were dissolved oxygen, total coliform, and copper (in Lake of the Arbuckles) (NPS 1997).

1.6.3 Fort Larned National Historic Site

- **Size:** 291 hectares (718 ac)
- **Elevation:** 600 meters (1,970 ft)
- **Waterways:** There is a 3.5-kilometer (2.2-mi) segment of the Pawnee River inside the administrative boundary of the park, and several kilometers of ephemeral and man-made or modified ditches and streams.

Fort Larned National Historic Site, situated on the Pawnee River floodplain in south-central Kansas, is located in the Great Plains Steppe ecoregion. It has a semi-arid climate and is located in a riparian area of former shortgrass prairie (now agriculture). The park was established to preserve and interpret the 19th century U.S. Army Fort Larned and the Santa Fe Trail.

The Pawnee River flows intermittently, with intermittent pools. The river was perennial in the past but an increase in agriculture in the watershed since the 19th century, and the construction of many dams and impoundments over the last 100 years, have changed its flow regime and sedimentation pattern, decreasing flow and increasing elevation of the streambed.

The major threat to the stream is extended periods of low or no flow. The decrease in flow has significantly reduced the water quality and extent of habitat for fish and amphibians in the park. The remaining pools are shallow, warm, and turbid, and favor species that can subsist in this habitat. The frequent drying of the entire stream reach at the park since 2004 has decreased the number of fish taxa found at the park (Delisle and Busby 2004).

1.6.4 Lake Meredith National Recreation Area and Alibates Flint Quarries National Monument

- **Size:** Lake Meredith NRA, 18,757 hectares (46,349 ac); Alibates Flint Quarries NM, 555 hectares (1,371 ac)
- **Elevation:** Both units, 1,000 meters (3,280 ft)
- **Waterways:** Lake Meredith NRA, 161 kilometers (100 mi) of perennial and ephemeral streams and the lake area; Alibates Flint Quarries NM, 12.2 km (7.6 mi) of ephemeral streams

Lake Meredith was formed in 1962, when the Bureau of Reclamation constructed the Sanford Dam on the Canadian River. It was designated as a National Recreation Area in 1990, and management was transferred from the Bureau of Land Management to the NPS. The lake was constructed to supply water to 11 surrounding communities, with recreational use as a secondary purpose.

The landscape at Lake Meredith NRA is characterized as rough and broken, and can be divided into two distinct areas: the upland area, including the mesa top, with a steep, gravelly slope; and the bottomland area surrounding the reservoir. Lake Meredith NRA is located in the Southwest Plateau and Plains Dry Steppe and Shrub ecoregion. Alibates Flint Quarries National Monument is located adjacent to Lake Meredith NRA.

Stressors on the water resources at Lake Meredith NRA include climate change increasing the intensity and duration of droughts, erosion and threats from oil and gas extraction in the watershed. Abundant agriculture in the watershed also has the possibility to impact the water quality and quantity (NPS 2008).

1.6.5 Lyndon B. Johnson National Historical Park

- **Size:** 273 hectares (674 ac)
- **Elevation:** 305–610 meters (1,000–2,500 ft)
- **Waterways:** The Pedernales River, a tributary to the Colorado River, flows through the park. Several other small streams and ponds are also located

within park boundaries, totaling 9.1 kilometers (5.7 mi) of perennial and ephemeral streams.

Lyndon B. Johnson NHP preserves the birthplace, boyhood home, ranch, and final resting place of the 36th president of the United States, as well as several other structures associated with the president and his ancestors. Lyndon B. Johnson NHP comprises two districts: the LBJ Ranch unit and the Johnson City unit, consisting of additional properties in Johnson City, Texas, both located in the Southwest Plateau and Plains Dry Steppe and Shrub ecoregion.

The Pedernales River has been significantly altered upstream by both the Hodges and Johnson Dam and by impoundments within the park. Although the river receives little recreation, such as swimming or boating, there is some fishing activity, and the river has been previously stocked in the state-park section of the LBJ Ranch unit.

Threats to the streams include an increase in flooding frequency and erosion, and decreases in water quality resulting from an increase in agricultural and residential development in the watershed. Town Creek, which runs through the Johnson Settlement portion of the park (part of the Johnson City unit), is subject to a decrease in water quality from the rapidly developing surrounding urban area (EARDC 2007).

1.6.6 Pecos National Historical Park

- **Size:** 2,699 hectares (6,670 ac)
- **Elevation:** 2,104 meters (6,920 ft)
- **Waterways:** Pecos NHP contains two main bodies of water: approximately 4.8 kilometers (3 mi) of the Pecos River, and a small portion of Glorieta Creek. Additionally, there are nearly 50 kilometers of ephemeral streams across all park units.

Pecos NHP was designated in 1965 to preserve an exceptional cultural and natural area with a long human history. The park lies in the upper Pecos River Valley, in the Rocky Mountain Steppe-Open Woodland-Coniferous Forest-Alpine Meadow Province, bor-

dered by the 3,962-meter (13,000-ft) Sangre de Cristo Mountains to the north, the rugged hills of the Tecolote Range to the east, and the steep Glorieta Mesa to the west. Glorieta Pass connects the Apache Canyon area and the northern Rio Grande Valley to the high plains and shortgrass prairie of New Mexico (Reed et al. 1999).

The Pecos River is the major tributary to the Rio Grande within the United States. It originates in the mountains of northern New Mexico, then flows southward through eastern New Mexico. Riparian environments along the Pecos River and Glorieta Creek are a rare resource in the arid American Southwest, and are critical to maintaining wildlife populations and water quality.

Major threats to park streams include mining, especially from mines in Tererro, New Mexico, and abandoned mines in the watershed. Nutrients are believed to be the current primary impact on water quality on the Pecos River. Possible sources of increased nutrient input include a fish hatchery upstream of the park, and recreational and residential development outside its boundaries. Both the town of Pecos and the Glorieta Baptist Conference Center operate wastewater treatment plants that discharge treated effluent into the Pecos River and Glorieta Creek, respectively (NPS 2008).

1.6.7 Sand Creek Massacre National Historic Site

- **Size:** 965.4 hectares (2,386 ac)
- **Elevation:** 1,208 meters (3,965 ft)
- **Waterways:** Sand Creek, an intermittent stream with quasi-perennial pools and several ephemeral streams, totaling 22 kilometers (14 mi).

Sand Creek Massacre NHS is located in southeastern Colorado. The site is located in the Great Plains-Palouse Dry Steppe Province ecoregion and is surrounded by agricultural lands and shrub scrublands. The site was created in 2000 to protect the site of a massacre of Native Americans in 1864. This location is of high cultural significance to the Cheyenne and Arapaho nations (EARDC 2007).

Threats to waters at Sand Creek Massacre NHS include decrease in surface and groundwater flow, surface-water withdrawal, and the creation of extensive impoundments in the watershed. An increase in the deposition of nutrients, herbicides, and pesticides during flow events is also possible, from increasing ranching and agriculture in the watershed (NPS 2008).

Naturally high levels of selenium are also likely present in the watershed. Flow events may entrain selenium particles that could be concentrated to acute levels as selenium contained in dust and soil are washed and deposited in the system (Struthers et al. 2013).

1.6.8 Washita Battlefield National Historic Site

- **Size:** 132 hectares (326 ac)
- **Elevation:** 589 meters (1,913 ft)
- **Waterways:** The park's major water resource is the Washita River (1.6 km).

Washita Battlefield National Historic Site, located in western Oklahoma, is a site on the banks of the Washita River. It is located in the Great Plains Steppe and Shrub ecological province. Park lands once consisted of mixed and shortgrass prairie, but were used for grazing and agriculture for more than 100 years (Struthers et al. 2013). The park protects and interprets the site where the 7th U.S. Cavalry, led by George A. Custer, attacked the Southern Cheyenne village of Chief Black Kettle in November 1868.

The Dust Bowl period of the 1930s greatly changed the Washita River, increasing sediment and altering channel morphology and flow patterns. In response, an extensive system of impoundments and levees was constructed in the watershed. These small impoundment structures, in addition to major dams on the Washita River, have led to a significant change in the river's slope, bed material, and sinuosity (Marston and Halihan 2007).

The Washita River headwaters overlay the Anadarko Basin, an area of major natural gas exploration. Petrochemical exploration and development in the watershed may threaten

water quality and quantity in the Washita River. Locally, disposal pits (evaporative ponds) for the saline-water byproduct of drilling are located two miles upstream and adjacent to the Washita River. The impact of recent extensive gas and oil drilling is unknown (Struthers et al. 2013).

The main threat to the site is reduction in flow to the river. The segment of the Washita River at the site is mainly a groundwater-fed reach. The current drought, and any in the

future—combined with groundwater withdrawal and any subsidence—may extend no-flow periods on the Washita NHS stream segment. The Washita River is listed on the Oklahoma 303(d) list for water quality impairment for turbidity. Extensive agriculture and ranching in the watershed has the possibility to increase the amount of nutrients, herbicides, pesticides, and sediments available for transport and deposition by the river (NPS 2008).

2 Project Goals and Measurable Objectives

The goal of SODN/SOPN streams monitoring is to detect broad-scale changes in aquatic and riparian ecological condition by observing selected ecological drivers, stressors, and processes, and to provide park managers with the data they need to make scientifically sound decisions about these resources. We will determine either the status (a mean or median value with measure of variation) or trend (change in metric value or time series of data) of the parameter or metric in the appropriate sample frame (index site, reach, or stream segment). The following sections describe the monitored parameters, based on network vital signs, and present monitoring objectives and measures associated with each vital sign.

2.1 Surface water quantity

We determine the status and long-term trends in surface water quantity by measuring stream discharge (cubic feet per second) and stage at monitoring sampling points (see Section 3.2.2) of network parks. To meet this objective, we will use continuous surface-water elevation and discharge data from station(s) in or near network parks to create a basic hydrologic characterization of the systems and allow for the evaluation of hydrologic impacts on riparian and water resources over the long term.

For perennial streams, we will determine the status of the following gauge metrics:

- discharge means and totals (annual, seasonal, and monthly),
- intensity of flood events (maximum discharge),
- frequency of flood and low/no flow events (i.e., return interval), and
- duration of low/no flow events.

We will determine status and trend in mean daily baseflow (annual and seasonal). We will determine the status of annual and seasonal gauge record statistics by comparison to gauge record statistics (e.g., gauge record or 30-year mean), when appropriate (Holmes and Dinicola 2010).

For intermittent or ephemeral streams, we will determine the status in timing, frequency, and duration of flow events. The hydro-period of sample units will be the main parameter measured. However, the length of time needed to detect trends in this parameter is not currently known. Once a sufficient amount of data is collected, the capacity to detect trend will be assessed.

2.2 Stream channel morphology

We will determine the status of stream-channel morphology by measuring total cross-sectional area, elevation, sinuosity, channel slope, and sediment composition of perennial stream reaches in network parks. To meet this objective, we will use methods described in Fitzpatrick and others (1998) to determine status of the stream habitat, and follow methods used by the USGS National Water-Quality Assessment (NAWQA) program (Turnipseed and Sauer 2010) to determine status of stream segments. These data will allow for (1) assessment of stream habitat and (2) comparison with similar sites across the park unit and region to other NAWQA sites.

2.2.1 Total cross-sectional area and elevation

Total cross-sectional area is the sum of incremental areas measured across the floodplain, and describes the channel form. We will determine the status and long-term trends in cross-sectional area (m^3) and elevation (longitudinal profile) of stream-channel bed surfaces. Additional resampling will occur in response to 100-year return-interval flood events or extreme, watershed-level disturbance (e.g., wildfire).

2.2.2 Sinuosity

Sinuosity is defined as the ratio between stream length and valley length (Rosgen 1996). We will determine the status of channel sinuosity in network parks every five years, or after significant ecological events in the watershed (e.g., wildfire). We will identify increases or decreases of 5% in stream sinuosity over five years.

2.2.3 Channel slope

Channel slope, or channel gradient, describes the change in channel elevation divided by the length of the channel. We will determine the status of channel slope in network parks every five years. Resampling will occur in response to 100-year return-interval flood events or extreme, watershed-level disturbance (e.g., wildfire). We will detect changes in stream slope greater than 5% over five years.

2.2.4 Sediment composition

Sediment composition refers to surface materials that occur on the bed and banks within the bankfull channel (Rosgen 1996). We will determine the status of fine particle composition (i.e., percent of total particles composed of fine sediment [<8 mm, D_{16} , D_{50} and D_{84}]) in riffle habitats of perennial streams every five years across the stream segment using standard pebble-count methods (Bunte and Abt 2001; Fitzpatrick et al. 1998).

2.3 Riparian vegetation

We will determine the status and long-term trends in riparian vegetation by measuring taxa frequency, richness, diversity, abundance, density, basal area, and community structure of native and non-native perennial plant species in riparian ecosystems of network parks. We will meet this objective by determining the status of the following parameter:

- **Vegetation community structure:** Vegetation community structure in riparian areas.

We will determine status and trend in the following parameters:

- **Vegetation life form abundance:** Vegetative cover (% by species and height class) of common native perennial species and frequency (by species) of uncommon native perennial species.
- **Recruitment of dominant species:** Density and basal area of dominant riparian tree species.
- **Exotic plants:** Vegetative cover (% by species and height class) and frequency

(by species) of non-native perennial and annual species.

2.4 Surface water quality

We will detect seasonal and long-term trends in surface-water quality by measuring core water quality metrics (see Section 2.4.1); concentration of nutrients, metals, and microorganisms; and physical properties of surface water in intermittent and perennial stream reaches. To meet this objective, we will document range and variability of water quality parameters under base flow conditions as they vary with seasonal and climatic variability; detect trend in water quality parameters (10% change in 5 years in the mean for core water quality parameters and selected other parameters with 80% power and 5% acceptable false-change [Type I] error); and compare water quality data against state criteria for acute and chronic exceedances on a quarterly basis.

2.4.1 Core water quality parameters

We will determine the status and long-term trends (daily, seasonal, annual, and long-term) in the concentration or value of water temperature, specific conductivity, turbidity, pH, dissolved oxygen, and discharge.

2.4.2 Nutrient dynamics

We will determine the status and long-term trends of nitrate, nitrite, ammonia, and nitrogen (total Kjeldahl); and total nitrogen and total phosphorus concentrations by measuring ammonia, total nitrogen, and total phosphorus in intermittent and perennial stream reaches of network parks.

2.4.3 Microorganisms (biological condition)

We will determine the status of *E. coli* by calculating the most probable number of *E. coli* colonies in intermittent and perennial stream reaches of network parks. We will also collect data on the status of biochemical oxygen demand and total organic carbon (both of which can indicate the status of organic systems in the stream system) and qualitatively assess physical and olfactory aspects of stream reaches.

2.4.4 Metals and metalloids

We will determine the status and long-term trends (seasonal and/or annual) in selected parameter concentrations in perennial (and selected intermittent) stream reaches by conducting seasonal and annual sampling of the following metals and metalloids:

Sampled seasonally (each quarter)	Sampled annually
<ul style="list-style-type: none">AluminumArsenicBoronCalciumCopperIronLeadMagnesiumManganeseMolybdenumPotassiumSilica (SiO₂)SodiumZinc	<ul style="list-style-type: none">AntimonyBariumBerylliumCadmiumChromiumNickelSeleniumSilverThalliumUraniumZinc

2.4.5 Carcinogens and toxins

Although toxins were identified as a SODN vital sign, we are not currently monitoring expressly for carcinogens and toxins. Many of the monitored parameters are considered either carcinogenic or toxic.

2.4.6 Suspended and total sediments

Sediments can have a direct impact on aquatic biology (e.g., direct acute toxicity) and ecology (e.g., reducing light penetration), and also impact other water quality measurements (Weiner 2008). We will determine the status and long-term trends in total suspended sediment, total dissolved solids, and turbidity through quarterly sampling.

2.4.7 General water quality and inorganics

In addition to the parameters identified by the vital signs, we will determine the status and long-term trends of additional inorganic (chloride, fluoride, sulfate) and general water quality parameters of (1) acidity and (2) alkalinity, bicarbonate, carbonate, and hardness (as CaCO₃). General and inorganic water quality parameters act as both complementary data to other parameters (e.g., hardness) and/or are parameters of interest themselves (e.g., sulfate).

2.5 Benthic macroinvertebrates

We will determine the status of community composition of benthic macroinvertebrates by measuring taxa richness, diversity, and abundance; and qualitative measures of physical habitat (flow class, erosion class, canopy cover, substrate classification, percent undercut banks, pebble count, presence of macrophytes, large woody debris, and the water profile) to aid in interpretation of macroinvertebrate data collected in perennial stream reaches of network parks. We will assess the status of macroinvertebrate communities and determine if they are attaining aquatic life use standards, using the appropriate state indices (Table 2-1).

2.6 Fish and other wildlife

Given current funding, the monitoring objective for fish and other wildlife is to identify the fish community in perennial reaches of network parks and/or their region. However, if funding and operational capacity become available, two additional objectives will be added: (1) determine long-term trends in native fish presence in perennial stream reaches

Table 2-1. State indices used to determine attainment of aquatic life standards.

State	Index	Source
Arizona	Warmwater Index of Biotic Integrity (<5,000 ft)	ADEQ (2015)
Colorado	Plains and Xeric Index	CDPHE (2010)
Kansas	Aquatic Life Use Support (ALUS) Index	KDHE (2012)
New Mexico	Low-elevation (<7,500-ft), Large Catchment (>149 mi ²) Index	Jacobi and others (2006)
Oklahoma	Summer Index Period	OWRB (2009)
Texas	TCEQ Critical Index Period	TCEQ (2014)

of network parks; and (2) determine long-term trends in presence of selected non-native aquatic species by measuring richness and diversity of fish species and presence/absence of other aquatic wildlife in perennial stream reaches in network parks. SODN and SOPN are exploring the possibility of

integrating datasets, monitoring methods, and techniques from the Arizona and New Mexico game and fish departments, the Environmental Protection Agency, and the U.S. Fish and Wildlife Service to effectively leverage ongoing sampling from these agencies.

3 Sampling Design

3.1 Overview

We are sampling the parameters identified in the previous chapter to provide park managers with an integrated understanding of ecological processes in network parks and create a dataset compatible with other federal and state monitoring efforts. Sampling is geared toward providing optimal statistical robustness and scientific rigor in a spatially and temporally efficient and comprehensive manner. An integrated monitoring approach allows us to evaluate changes among multiple parameters at the same locations within streams, and to determine and interpret parkwide condition and trends.

There are two levels of implementation in this protocol. The first level has included the selection and installation of an index sampling location at each park unit with perennial streams. The second level includes establishment of spatially distributed sampling locations across park units that include mainly ephemeral streams.

The initial index locations are sampled during each water year. Each index location provides inference to only that index location. The spatially distributed sampling locations are sampled in a panel design, with five sample locations sampled each year over a five-year period. These distributed locations provide inference for streams across an entire park.

3.1.1 Sampling design selection

Sampling designs fall into three broad categories: census, targeted/judgmental, and probabilistic (EPA 2002). In census designs, all units within a target population (e.g., all perennial streams within a park) are sampled. Due to the high cost of census surveys, few monitoring programs utilize these designs. Targeted, or judgmental, designs select monitoring sites based on representativeness or other selection criteria (e.g., ease of access, other established monitoring efforts). Targeted designs are common in aquatic resource monitoring, including the USGS NAWQA program (<http://water.usgs.gov/nawqa/>).

Probabilistic designs, or statistical surveys, use monitoring sites that are selected in a statistically random manner. Randomization ensures that sites are selected without bias or judgment. The probability that a given site will be selected is known, so inferences can be made about the population from the sample. Probabilistic designs are becoming increasingly popular and are used by the EPA and by several other I&M networks (NPS 2008; NPS 2010). Many aquatic monitoring programs use more than one sampling design to address multiple objectives (Gilliom et al. 2014).

The Sonoran Desert and Southern Plains networks use two sampling designs to monitor aquatic and riparian communities in select network parks:

1. **Targeted sampling:** At least one stream segment is selected from perennial, intermittent, or ephemeral stream segments (see Section 3.2.3.1) located at existing water-quantity (e.g., USGS stream gauges) and water quality sampling sites at each park unit.
2. **Probabilistic sampling:** For park units with more than 10 kilometers of perennial, intermittent, or ephemeral stream length, we also use a probabilistic sampling design that draws random, spatially balanced samples at a sub-watershed (HUC 12) scale.

The ultimate goal of this sampling design is to provide inference to all streams (perennial, intermittent, and ephemeral) and adjoining riparian areas in a park. It will not be possible to provide this scale of inference for all vital signs and composite parameters. For example, water quality is not sampled in ephemeral streams.

3.1.2 Targeted sampling

Targeted sampling is used at all network parks where perennial, intermittent, and ephemeral streams are monitored. The initial implementation goal of the protocol was to establish one targeted monitoring site in each

park unit with perennial streams to provide park managers with meaningful information about the aquatic and riparian resources at that park unit.

On perennial streams, targeted monitoring sites are established near active streamflow gauges, at sites where streamflow gauges can be installed, or at sites with a history of water quality data. For intermittent and ephemeral streams, targeted monitoring sites are established at sites with easy access, a history of monitoring data, or particular management concerns. One targeted stream site has been identified in each SODN/SOPN park unit where streams are monitored.

3.1.3 Probabilistic sampling

Probabilistic sampling is used at park units with more than 10 kilometers of perennial, intermittent, and ephemeral stream length (see Appendix A). We use the Generalized Random Tessellation Stratified (GRTS) design (Stevens and Olsen 2004) to spatially allocate sample units within the sampling frame. The GRTS approach produces a design that is spatially well-balanced, probability-based, flexible, and simple (Stevens and Olsen 2004). Because it tries to maximize the spatial independence between monitoring sites, the spatially balanced sampling design should provide more information per site, thus increasing efficiency (Stevens and Olsen 2004).

Spatially balanced designs, such as GTRs, are increasingly being applied to ecosystem monitoring because they provide the advantages of a probabilistic design (Stehman 1999) and ensure spatial balance regardless of overall sample size. GRTS designs facilitate adding or removing sites in a spatially balanced manner if statistical power, financial considerations, or additional monitoring objectives warrant adjusting the sample size. This scaling ability is an important advantage because future changes in technology, objectives, and budgets may necessitate increasing or decreasing sample sizes.

Every sample unit within the sampling frame (i.e., target population) has an equal chance of being selected. Sites are selected from the target population using equal probabilities

with stratification, as appropriate. In general, 20 potential sampling sites (with an oversample of 20 sites) are generated for each frame, with the intention of establishing 5–10 monitoring sites. The sites are evaluated sequentially in the field before final selection.

Probabilistic sites are sampled every five years in a rotating panel design. The rotating panel design allocates sites annually, such that each site is revisited every five years [1,4]. The total population of sites is apportioned evenly among years (e.g., 10 sites over a 5-year period = 2 sites/year). The advantages of this design are that (1) the influence of interannual variation (“noise”) is less pronounced for the analysis of five-year trends and (2) there are tremendous efficiency gains from the perspective of fielding and funding sampling crews, as effort is spread evenly over the five-year intervals. The disadvantages are that (1) the effects of individual stochastic events may be difficult to evaluate and (2) detecting trends requires at least 10 years of data collection (i.e., ≥ 3 sampling intervals for all sites).

For small, relatively accessible park units, we sample all sites within the same year, and do not sample again until the five-year interval is complete.

3.1.4 Protocol modules

SODN/SOPN streams monitoring employs a modular design, permitting adaptation of the protocol to different flow regimes and changes in resources and priorities over time while still providing a level of information that will allow for determination of status and trend. The modules are composed of carefully selected standard techniques and methods developed by the USGS, EPA, and other agencies and organizations, and adapted for use at each park unit to meet program goals. Using standard methods allows for a more rapid implementation of monitoring, and the ability to compare results across the watershed and region. The current assembly of modules (Table 3-1) is considered to be the most basic level of implementation that will provide an understanding of ecosystem processes in aquatic and riparian areas of SODN/SOPN parks.

Table 3-1. Implementation models according to stream type.

Module	Name	Perennial	Intermittent	Ephemeral
Module 1	Surface water quantity	X	X	X
Module 2	Stream channel morphology	X	X	X
Module 3	Riparian vegetation	X	X	X
Module 4	Surface water quality	X	X*	—
Module 5	Benthic macroinvertebrates	X	X*	—
Module 6	Fish and other wildlife	X	—	—

*A lesser level of implementation—this may include decreasing the spatial extent of sampling, or limiting the number of samples due to the duration, timing, or extent of the flow events.

Although the implementation regime as suggested in Table 3-1 is ideal, in some situations it may not be possible or financially feasible. When not possible, the project lead, program manager, and park staff will plan the most efficient module combination to provide the information needed to best achieve program goals.

3.2 Spatial design

3.2.1 Target population

The SODN/SOPN streams protocol provides data on the most common stream types in network park units: perennial, intermittent, and ephemeral. *Perennial* streams or reaches flow continuously throughout the year or most of the year, and their upper surfaces generally stand lower than the water table in the region adjoining the stream (Stromberg 2001). *Intermittent* streams or reaches flow only at certain times of the year, when they receive water from springs or from a surface source. *Ephemeral* streams or reaches flow briefly, only in direct response to precipitation in the immediate locality. Their channels are above the water table at all times.

3.2.2 Sampling frames

Streams within network parks are placed into three sampling frames based on their flow regime (i.e., target population), as derived from the USGS National Hydrography Dataset (USGS 2014):

1. **Perennial streams:** This sampling frame includes all wadeable stream segments >150 meters in length classified

as perennial.

2. **Intermittent streams:** This sampling frame includes all wadeable stream segments >150 meters in length classified as intermittent.
3. **Ephemeral streams:** This sampling frame includes all wadeable stream segments >150 meters in length classified as ephemeral.

Some streams are excluded from the sampling frame due to issues of safety, access, or other management concerns. Streams that meet at least one of the following conditions are excluded:

- Have extensive modification or diversion and are managed as a cultural resource or for something other than natural resource character (e.g., the irrigation canal at Montezuma Well),
- Surrounding watershed constitutes less than 5% of park area,
- Stream gradients are >15% and surrounding gradients >30% (for crew safety), or
- Require excessive hiking time (>2 hours) to reach the site

3.2.3 Sample units

The basic sampling unit for the protocol is the stream segment (see Section 3.2.3.1): a fundamental geomorphic unit, strongly influenced by proximate landforms, soils, and hydrology, as well as by upstream and watershed factors identified by Horton (1945) and Strahler (1957), and used in many later

stream and watershed evaluations (e.g., Frisell et al. 1986). In this protocol, stream segments are defined as stream lengths of >150 meters that are bounded by another channel, tributary, or an administrative boundary.

Within each stream-segment sample unit, protocol modules (see Section 3.1.4) are implemented at varying spatial and temporal scales. These spatial scales include the stream segment (see Section 3.2.3.1), index reach (see Section 3.2.3.2), and index site (see Section 3.2.3.3), each decreasing in spatial inference (Table 3-2, Figure 3-1). A brief introduction to the spatial configuration of sampling locations is provided below. Temporal sampling designs range from quarterly to every five years (Table 3-2, Section 3-3).

The scope of inference for the different spatial scales under different sample designs must be clearly understood. For targeted sites, the valid statistical inference is to the specific stream segment, index reach, or index site. Under the probabilistic design, the inference is to the entire sampling frame.

3.2.3.1 Stream segment

The stream segment is a relatively homogeneous (physically, chemically, and biologically), >150-meter length of stream bounded by a tributary, administrative boundary, or other geographic feature (Fitzpatrick et al. 1998). Stream segments can be selected in a targeted manner or as part of a probabilistic design. Segments selected using a targeted approach provide statistical inference to only that segment. Segments selected using the probabilistic design provide statistical inference to segments within that sampling frame (e.g., perennial stream segments in a park

unit), allowing for assessment of the status and long-term trends in parameters across the landscape.

Stream-channel morphology and riparian vegetation are monitored at the stream-segment spatial scale (see Table 3-2). Each stream segment is divided by up to 11 equally spaced cross-sections that form the foundation for the stream-channel morphology and riparian-vegetation measurements. Measurements of longitudinal profile and substrate are conducted along the entire stream segment. Line-point intercept transects and frequency plots for riparian vegetation are arranged parallel to the streamflow along each channel cross-section within three zones based on distance from the active channel. Vegetation transects are located using an equal-probability GRTS design, allowing for spatially balanced dispersal of transects across the riparian zone.

3.2.3.2 Index reach

Within each stream segment is one index reach, generally a 100–300-meter stretch of stream (depending on segment geography). The index reach corresponds to monitoring reaches used by the EPA and USGS NAWQA programs, and state departments of environmental quality. This allows for valid comparison of SODN/SOPN data with data collected by other agencies. Data on benthic macroinvertebrates, fish and non-native animals, and habitat are collected at this spatial scale. Two macroinvertebrate samples are collected. One set is collected following individual state methods. Another is collected across the reach proportionally from each microhabitat (e.g, run, riffle).

Table 3-2. Spatial and temporal scale of streams monitoring modules.

Module	Spatial scale (sample unit)	Temporal scale (sampling frequency)
Surface water quantity	Index site	Quarterly/continually
Stream channel morphology	Segment	Five years*
Riparian vegetation	Segment	Five years*
Surface water quality	Index site	Quarterly/continually
Benthic macroinvertebrates	Index reach	Annually
Fish and non-native animals	Index reach	Annually

*with the contingency of resampling after a ≥100-year flood event



Figure 3-1. Example of configuration of stream segment, index reach, and index site.

3.2.3.3 Index site

Also within each stream segment—preferably, within the index reach—is an index site where continuous stream discharge (water quantity) data are collected, either at a USGS stream gauge (e.g., Beaver Creek), or an NPS monitoring installation (e.g., Wet Beaver Creek). Water quality samples are collected at the index site. In the targeted design, it must be noted that stream discharge and water quality data collected at the index site provide statistical inference to that site only—not across the index reach or the entire stream segment.

3.3 Sampling frequency and timing

Sampling frequency and timing are a function of the biogeochemical, geomorphological, and hydrological phenomena of interest, the desired power to detect trends over time, and

the pragmatic constraints (time and money) of sampling effort. Sampling frequency may be adjusted in the future to optimize the balance between statistical power to detect trends and the high cost of data collection and processing. Because each of these factors varies over the suite of vital signs monitored in SODN/SOPN streams, we employ four nested sampling frequencies (continuous, quarterly, annual, and every five years) for the 11 vital signs of interest, grouped into six modules and summarized in Table 3-3.

3.3.1 Continuous

The USGS and the NPS Water Resources Division operate continuous-streamflow gauging stations in and near network parks. For some gauges, real-time data are available. SODN/SOPN streams monitoring uses these

Table 3-3. Frequency, timing, and measures of streams monitoring.

Module	Continuous	Quarterly ¹	Annual		Every five years ²	Measure(s)
			Late spring or fall	August		
Surface water quantity	X	–	–	–	–	Streamflow (cfs)
Stream channel morphology	–	–	–	–	X	Cross-sectional area, longitudinal profile, pebble count
Riparian vegetation	–	–	–	–	X	Foliar cover (%) by species and height class, frequency by species
Water quality	–	–	–	–	–	Water temperature, dissolved oxygen, pH, turbidity, specific conductance, discharge
(Core parameters)	–	X ³	–	–	–	
Primary nutrients	–	X ³	–	–	–	Ammonia, total nitrogen, total phosphorus
Metals/inorganics	–	X ³	–	–	–	Concentration per unit water
Biological condition	–	X ³	–	–	–	Biochemical oxygen demand (BOD), <i>E. coli</i> , qualitative physical and olfactory description
Suspended (and total) sediments	–	X ³	–	–	–	Concentration per unit water
General water quality and inorganics	–	X ³	–	–	–	Concentration per unit water
Benthic macroinvertebrates	–	–	X	–	–	Relative abundance by family, qualitative measures of physical habitat (flow class, erosion class, canopy cover, substrate classification, percent undercut banks, pebble count, presence of macrophytes, large woody debris, water profile, and undercut banks
Fish and crayfish	–	–	X	–	–	Presence/absence

Index sites and reaches are sampled every year. Index segments are sampled every five years.

¹Pre-monsoon (April–June), monsoon (July–August), post-monsoon/pre-winter rains (September–October), post-winter rains (November–March)

²Autumn or winter

³On intermittent streams, water quality measurements are taken annually instead of quarterly.

data and derived information to meet monitoring objectives. We also deploy instruments that collect continuous data on water level and water quality, and use these data to assess status and trends in applicable metrics.

3.3.2 Quarterly

Most water quality measures (biological condition, primary nutrients, alkalinity, core water quality parameters) are sampled each quarter, as recommended by the Arizona Department of Environmental Quality (ADEQ 2011). Using a securely mounted, multiparameter sonde, core parameters are sampled “continuously” for at least two weeks each quarter, at each index site, at a sampling interval of 15 minutes. Each parameter is expected to respond relatively rapidly to changes in water condition daily, seasonally, and annually. Therefore, the additional cost of quarterly sampling is warranted. It is likely that adjustments will be made after a thorough review of data from the first few years of collection. For example, if nutrient levels are stable throughout the year, then collection of primary nutrient samples may be reduced from quarterly to annually. For efficiency, these sampling events will be concomitant with the annual and bi-annual sampling trips.

3.3.3 Annual

Benthic macroinvertebrates and fish are sampled during the state index period for bioassessment monitoring. Several chemical parameters (pollutant metals, carcinogens, toxins) can be effectively sampled during the warm summer months following the onset of the monsoon (see Section 2.4.4; ADEQ 2011; Sprouse et al. 2004). These parameters are monitored only annually, either because they are considered to have low within-year variance, such variance has little biological meaning in the context of park management, or increasing sampling intensity is cost-prohibitive.

3.3.4 Five-year cycle (with contingency)

Channel morphology and riparian vegetation respond to routine maintenance flows and infrequent but extreme flooding events. Surveying every five years should document

important morphological and riparian vegetation community changes due to the former, based on previous research and monitoring efforts in the arid Southwest (Moody et al. 2003). Channel morphology is surveyed during the winter or spring. Riparian vegetation is monitored during the late spring/summer. Additional samples are collected to capture important extreme flooding events (e.g., greater than 100-year flood). Initiation of these additional “contingency monitoring” sampling periods is based on gauge records, precipitation data, and the occurrence of substantial management and natural disturbances in the watershed. This information is collected and reviewed periodically to inform the need for monitoring channel morphology and vegetation outside the five-year cycle.

3.3.5 Power analysis

Adequate sample size is important for determining our ability and confidence in detecting a trend of a given magnitude. Power to detect trend in univariate parameters can be estimated before initiating sampling (a priori) using legacy data, and refined during the first few sampling intervals (Hubbard et al 2012).

This protocol proposes to detect trends in the data associated with parameters in the riparian vegetation and water quality modules (see Sections 2.3 and 2.4). Power analysis was conducted on pilot data to ensure that proposed methods can detect trends in data.

3.3.5.1 Riparian Vegetation

Adequate sample size (n) for detecting a trend of a given size across a landscape with permanent plots is determined by the following equation (from Herrick et al. 2005a):

$$n = \frac{(S_{diff})^2 (Z_{\alpha} + Z_{\beta})^2}{(MDC)^2}$$

Where:

- S_{diff} = Standard deviation of the differences between paired samples,
- Z_{α} = Z-coefficient for false-change (Type I) error,
- Z_{β} = Z-coefficient for missed-change (Type II) error, and
- MDC = minimum detectable change size.

Pilot data for riparian vegetation on perennial streams were collected from Tumacácori NHP, Montezuma Castle NM, and Pecos NHP. One set of pilot data was available to estimate power of riparian vegetation monitoring methods for xeroriparian vegetation found on ephemeral streams at Organ Pipe Cactus NM. In this case, the need exists to estimate inter-sample variability from the existing data. We use:

$$S_{diff} = (S_1)(\sqrt{2}(1 - corr_{diff}))$$

Where:

- S_{diff} = estimated standard deviation of the differences between paired samples,
- S_1 = sample standard deviation for first sample period, and
- $corr_{diff}$ = correlation coefficient between samples in successive sample periods.

The pilot riparian vegetation data indicated that a sample size of 20 was sufficient to detect a 10% change in, on average, three sample events (SODN 2018) for common (>10% cover) plant taxa by structural layer.

3.3.5.2 Water quality

This protocol uses seasonal Kendall Tau analysis for trend analysis of water quality samples (Helsel and Hirsch 2002). The Sonoran Desert Network conducted a power analysis study examining discrete water quality samples (Lindsey 2010) to determine the sampling frequency that would detect trends most efficaciously for the parameters sampled by the protocol. This study used existing long-term water quality measurements from the Sonoran Desert region to model the capability of various temporal scales of data collection. The study compared the capacity of monthly, quarterly, and annual sampling schemes to detect trend.

Overall, the study indicated that a monthly sampling regime detected significant trends in the least time. However, using a quarterly sampling scheme of hydrologic seasons (NPS 1995a, 1995b, 1998a, 1998b, 1999, 2001, 2003) rather than calendar seasons resulted in the detection of 87% of the trends detected by monthly sampling in the same amount of time, while costing an estimated 33% of monthly sampling.

Lindsey (2010) indicated that the quarterly sample design using hydrologic seasons could detect a 10% change in parameter concentration on a 20-year trend, on average, in 5.3 years. For annual sampling, the ability to detect a 10% change in parameter concentration on a 20-year trend is 9.7 years.

3.4 Similarities to other designs

Most streams-monitoring efforts in the American Southwest select one or more “representative” sites for establishing permanent sampling reaches (e.g., Harrelson et al. 1994). Selection criteria are generally driven by the perceived level of stream instability and relationship to a specific management issue (e.g., proximity to a bridge or grazing allotment). The preference for this subjective approach likely stems from the high proportion of studies that are focused on channel inventories or “snapshot” rapid assessments.

Like other designs, this protocol uses targeted and probabilistic approaches to most efficaciously meet its objectives. It uses proven standard methods and procedures developed by federal and state agencies (e.g., EMAP, ADEQ and NAWQA programs). The methods have been modified to reflect the particularities of network parks, as well as the goals and objectives of this monitoring program.

4 Field Methods

Field sampling generally follows existing methodology (e.g., USGS, EPA) when appropriate, modified for conditions at sampling sites in the Southwest.

4.1 Surface water quantity

Surface-water quantity (stream discharge in unit volume/time) is measured at gauging stations maintained by the USGS, state water resource divisions, or SODN/SOPN. Some stations already exist and are operated by other agencies. Others are installed by SODN/SOPN. Measurements at these stations include both discrete and continuous measurements. Discrete measurements occur during a specific time period; for example, during a sampling visit. Continuous measurements use a water-level sensor (e.g., bubbler system) to collect a data point automatically every 15 minutes. Continuous measurements are logged and/or transmitted with telemetry.

4.1.1 Stream discharge

4.1.1.1 Discrete measurements

Discrete stream-discharge measurements are collected at least four times each year, when discrete water quality samples are collected (see Section 4.4). These discharge measurements are invaluable for interpreting water quality results and creating accurate rating curves (models for calculating stream discharge) for SODN/SOPN index sites. The primary equipment for collecting discrete stream discharge is an acoustic Doppler velocimeter. Other equipment can also be used, such as a pygmy current meter. Information regarding acceptable equipment can be found in Turnipseed and Sauer (2010). Techniques for collecting discrete discharge measurements follow the recommendations in the USGS publications by Turnipseed and Sauer (2010).

4.1.1.2 Continuous measurements

SODN/SOPN seeks to locate one stream gauge collecting continuous data in the targeted index segment in each monitored park. At some index sites, a USGS gauge station is already installed. At others, SODN/SOPN currently collects continuous stage data us-

ing logging pressure transducers or other methods.

Continuous measurements of stream stage are collected with equipment that can accurately and reliably record water levels every 15 minutes. Siting, selection of instrumentation, installation, and management of these devices follow USGS recommendations found in Turnipseed and Sauer (2010) for perennial and intermittent streams, and Smith and others (2010) for ephemeral systems. Technology, equipment, and methods generally follow USGS methods, as outlined in Turnipseed and Sauer (2010), Rantz and others (1982a; 1982b), and Smith and others (2010), with careful consideration to available resources and safety.

Three types of stream-gauging stations are found in SODN/SOPN parks:

1. *Gauges installed and operated by the USGS, or state agencies following protocols created by or derived from USGS protocols.* SODN/SOPN will typically act in a support role at these stations and download certified data from these gauges from the National Water Information System (<http://waterdata.usgs.gov/nwis>) for use in analysis.
2. *Gauge stations installed and operated by SODN/SOPN and associated NPS staff where USGS gauges are not present.* These stations are implemented in perennial and quasi-perennial, intermittent, and ephemeral stream-segment index sites. These gauges are established following USGS criteria and features, as closely as possible, described in Turnipseed and Sauer (2010) and Smith and others (2010), including unchanging natural controls that promote a stable stage-discharge relation, a satisfactory reach for measuring discharge throughout the range of stage, and the means for efficient access to the gauge and measuring location (Turnipseed and Sauer 2010; Smith et al. 2010; Rantz et al. 1982a, 1982b; Kennedy 1984; Fong et al. 2011). These gauge stations include a permanently mounted staff gauge (or

non-contact equivalent) to measure stream stage, and at least two crest-stage gauges, both installed to USGS specifications (Turnipseed and Sauer 2010) to determine peak flow discharge. For quality control, these gauges are inspected, repaired, and surveyed for elevation annually, or following extreme flow events (Kenney 2010).

3. ***Gauge stations that collect a reduced level of data (e.g., streamflow hydroperiod).*** Tertiary stations currently include most probabilistic sample sites for ephemeral streams, including a temperature sensor/logger to determine hydroperiod. These continuous loggers are deployed at the index site on selected stream segments.

4.1.2 Data telemetry

One goal of the SODN/SOPN program is to enable near real-time retrieval of data using telemetry. This informs managers of any station malfunction, allowing repairs to occur quickly in order to minimize data loss. It also enables communication of stream stage and discharge to park managers, cooperators, and the public in a timely fashion. SODN/SOPN currently uses the GOES system of satellite communication (Turnipseed and Sauer 2010), and serves the data on the Climate Analyzer website (<http://www.climate-analyzer.org>).

4.2 Stream-channel morphology

Field methods for monitoring stream-channel morphology include channel cross-sections, longitudinal surveys, and pebble count. A transit total station (an optical instrument used in surveying) and survey-grade GPS are used to survey the cross-section and longitudinal profiles. The total station determines the distance and angle from itself to a location and then computes the three dimensional coordinates (northing, easting, and elevation—i.e., X, Y, and Z). In the future, technologies including aerial or ground-based LIDAR may be considered for use. The goal for quality control with new technology should be sub-centimeter accuracy in the X, Y, and Z.

4.2.1 Channel cross-sections

A channel cross-section is a cross-sectional view of the river channel that spans the entire flood-prone width and extends into areas dominated by terrestrial vegetation. For each selected stream segment (perennial, intermittent, and ephemeral), up to 11 channel cross-sections, at least 30 meters apart, are systematically located (evenly spaced) within the segment, perpendicular to the direction of flow. A random start point is generated along the first 50 meters of stream thalweg (deepest point in the channel).

4.2.2 Longitudinal profile

A longitudinal profile of the sampling reach, shot with the total station, measures the elevation of the thalweg, water surface, habitat types, features, and terraces. Measurements are made until the entire sampling reach is characterized (Harrelson et al. 1994). This profile is used to determine the water slope and channel slope of the sampling reach. The longitudinal profile survey also provides a detailed planform view of the stream.

4.2.3 Pebble count

A modified Wolman pebble count quantitatively describes the substrate composition of the reach. A minimum of 250 particles (Harrelson et al. 1994) are measured along the stream segment within the low-flow channel. The intermediate axis size category (neither the shortest nor the longest measurement) is determined using a gravelometer. Embedded and large particles are measured in place (Harrelson et al. 1994).

4.2.4 Habitat assessment

During the survey of the stream segment, a variety of metrics are collected at each cross-section corresponding to NAWQA habitat-assessment methods (Fitzpatrick et al. 1998). These measurements allow the status of the stream segment to be characterized, and for comparison of metrics between segments in the park and region (i.e., other NAWQA sites).

4.3 Riparian vegetation

Riparian vegetation monitoring in this protocol is designed to determine status and detect trends in the frequency, abundance, and density of vegetation found in the streams and adjacent riparian areas. It also identifies and tracks vigor metrics for large trees.

Riparian zones of streams can be dynamic areas, with frequent changes in the location of the stream as the channel and riparian area respond to floods, fires, and other events. This design adapts to these possible changes. The basic sampling unit is the entire segment, and the permanent sampling features of the design are the cross-sections (see Section 4.2.1). Using the transects as the permanent feature is a “hedging of bets” tactic leveraging the increased power of permanent plots (Elzinga et al. 1998) against the typical dynamic nature of streams and associated riparian systems.

As changes occur across the riparian zone, sampling can adapt in an ordered way, focused on the parameter of concern, without compromising the capacity to detect change. For example, riparian-zone vegetation (i.e., vegetation found >10 m from the active stream channel and up to the upland boundary) is sampled on transects located on the cross-sections. Statistics are generated from these vegetation data, which are collected at transects across the segment to assess the abundance and frequency of riparian zone taxa.

If the river changes path in the segment, and a particular transect is subsequently located in an active channel, that transect can be replaced with a new sampling transect selected as part of an “oversample” during the initial set-up of vegetation monitoring on that segment. This allows for valid, stable sample size throughout the study.

The basic sample unit of this protocol module is the stream segment. The sampling methods described below are based on the cross-sections described in the channel-morphology protocol module (see Section 4.2).

4.3.1 Aquatic macrophytes

To determine frequency of invasive, faculta-

tive, and obligate wetland (and other xeric-facultative) plants in the wetted area of the stream segments, we identify and determine the number of discrete plant taxa located in a 20 × 20-meter wetted-width plot centered on each cross-section (e.g., Elzinga et al. 1998).

4.3.2 Greenline vegetation

A 20-meter transect is established on the greenline (the first line of perennial vegetation along the bank of the stream) of both stream banks along each cross-section. The line-point intercept method (Elzinga et al. 1998) is used to measure vegetation cover on the greenline transect. Line-point intercept measures the number of “hits” of a given species out of the total number of points measured. Vegetation is recorded within three height categories along each transects, with points spaced every meter (20 points total). The three height categories are field (0.025–0.5 m), subcanopy (>0.5–2 m), and canopy (>2 m). Perennial vegetation is recorded to species. Annual vegetation is recorded to lifeform, with the exception of a suite of annual, non-native plants that are recorded to the species level. Soil cover is recorded to substrate class (e.g., gravel, cobble, litter). In addition, one meter on either side of the transect is searched for presence of all taxa not captured by the point-intercept transect. These data are used to measure frequency of less common species.

4.3.3 Riparian-zone vegetation

Riparian-zone sample transects are established on the segment cross-sections. Ideally, 40 spatially balanced, randomly selected transect locations are selected for each stream segment. The goal is to use 20 transects, with an oversample of 20 to accommodate locations that do not meet sampling criteria (see riparian vegetation monitoring SOP) and eventual changes in the location of the river on the floodplain. A 20-meter transect is established at each selected point, centered on the cross-section and parallel with the stream. If an individual transect cannot be read (e.g., for reasons of safety or proximity to an existing transect), then the next transect is used.

This design ensures an independent, random sample, with transects evenly distributed on the cross-sections throughout the segment. The line-point intercept method (see Section 4.3.2) is used to measure vegetation cover on the riparian transects. In addition, one meter on either side of the transect is searched for presence of all taxa not captured by the point-intercept transect. These data are used to measure frequency of less-common species.

4.3.4 Riparian vegetation density

Measuring the density of dominant tree and shrub taxa in the riparian zone helps us to understand overall ecological processes and whether the dominant vegetation, trees, and shrubs are successfully regenerating. A nested density plot, with plot sizes of 20 × 50 meters, 10 × 25 meters, 10 × 10 meters, and 1 × 1 meter for varying vegetation size (Figure 4-1) is established on each greenline transect on either side of the river. The area sampled and number of stems for each vegetation size class are summed from all density plots for the entire stream segment. Poles per hectare and basal area per hectare (by vegetation size class) are reported by species.

4.3.5 Legacy trees

Legacy trees are large trees (>50 cm diameter at breast height) that are typically dominant features of the riparian landscape. These trees are an indicator of past and current ecological processes at work in the stream segment, and may be historically significant. Field crews map the location of these legacy trees and collect basic vigor metrics on each (e.g., height), as well as notes on factors such as flood scars and illness.

4.4 Surface water quality

4.4.1 Overview

Field and laboratory methods follow methods recommended by the USGS field manual (USGS n.d.) and the NPS Water Resources Division (Irwin 2008).

Discrete measurements of core water quality parameters (temperature, specific conductivity, pH, and dissolved oxygen) are collected using a handheld, multiparameter water quality instrument. These measurements occur, at a minimum, during quarterly sampling events.

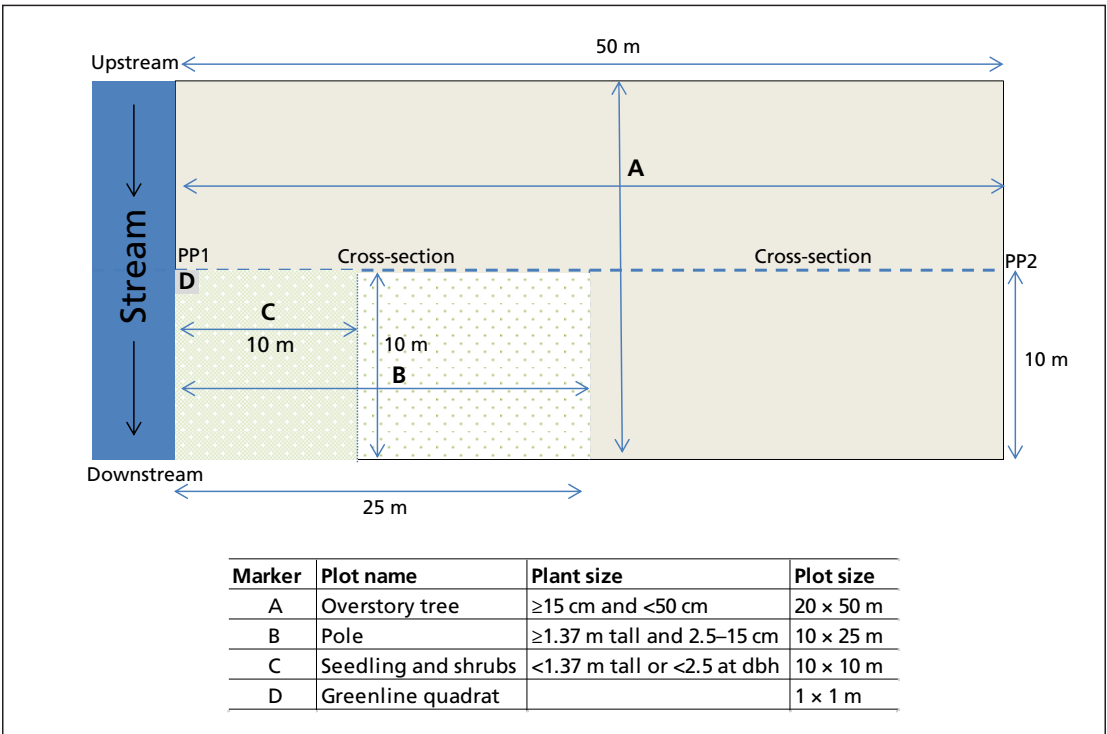


Figure 4-1. Layout of the riparian vegetation density plot, with indication of location of subplots and size of vegetation sampled in each subplot.

Continuous measurements of core water quality parameters are collected using a datalogging multiparameter water quality instrument for periods of several weeks each quarter.

All other water quality measurements (primary nutrients, alkalinity, biological condition, and pollutant metals) are taken from grab samples for analysis either at the contracted lab (i.e., TestAmerica labs, www.testamericainc.com) or immediately in the field. The Test-America laboratory is certified by the National Environmental Laboratory Accreditation Program (NELAP), as required by the NPS Water Resources Division. Appendix B lists analytes and methods.

4.5 Benthic macroinvertebrates

4.5.1 Sample collection

Sample-collection methods for benthic macroinvertebrates follow USGS methods and those of the state where the index reach is located (Moulton et al. 2002).

Two types of samples are collected in each index reach:

- Following appropriate state methods, samples are collected from targeted riffle habitats to provide estimates of abundances of organisms.
- Following Moulton and others (2002), a sample is collected to develop a list of species present in the reach. Using nets, samples are actively collected from all habitat types within each sampling reach and compiled into one composite sample.

For each of the quantitative targeted riffle microhabitats, depth, velocity, particle size, and particle embeddedness are measured. Wetted and active channel widths, water depth,

velocity, and canopy closure are measured at 16 points along each transect. For the entire index reach, the length of habitat type (riffle, run, glide, pool) is identified. Physical habitat data are collected at three spatial scales: microhabitat, transect, and index reach. A detailed description of sampling methods can be found in Brasher and others (2011) and in SOP 26.

4.5.2 Analysis

Aquatic macroinvertebrate samples are sent to the Bureau of Land Management/Utah State University National Aquatic Monitoring Center (i.e., the BugLab) at Utah State University in Logan, Utah. There, a taxonomist certified by the North American Benthological Society identifies all aquatic macroinvertebrates to the lowest possible practical level (typically, family or genus).

4.6 Fish and other wildlife

SODN uses fish-survey data collected by the Arizona Department of Game and Fish and other agencies. Fish surveys are conducted at locations across the state annually in the fall, according to the Standard Fish Sampling Protocol for State of Arizona Waters (AGFD 2004). Electrofishing equipment, seines, and dipnets are used to conduct spot-check surveys for fish and determine the presence and absence of native and exotic fish species and species composition at each site. All fish habitats present are sampled, including pools, riffles, runs, backwaters, and areas with overhanging vegetation along banks. Sampling effort is measured as number of seines, number of dipnets, time spent sampling, and approximate length of stream sampled. The following are noted for all captured fish: species, age (adult or juvenile), capture method (electrofisher, seine, dipnet), and habitat. Fish are not weighed or measured for total length.

5 Data Management

Effective data management to ensure data quality, interpretability, security, longevity, and availability is critical to the success of the streams monitoring program. Data management for this monitoring effort encompasses a multi-year cyclic process that starts in September and continues for approximately 18 months.

This section presents an overview of the monitoring database and general procedures for organizing, entering, verifying, validating, certifying, documenting, distributing, and archiving the data collected under this protocol. Additional information and context may be found in each network's data management plan. Further details and instructions for the tasks in each stage of the data-management cycle are contained in the SOP for data management.

5.1 Data organization

This long-term monitoring project generates large quantities of data and numerous products. A well-organized digital file structure is critical to avoid confusion and potential data corruption. Appropriate staff and partners involved in this project are granted edit access to data for the current field season. At the end of each field season, certified data, completed products, and other seasonal files are transferred to the permanent project folder, where they are stored in read-only format. Each network will provide documentation and training on its own specific directory structure, its purpose and use, and links to other information relevant to the project.

5.2 Data model

To appropriately manage streams data, the dataset should be stored and managed in a normalized relational database. This protocol may also leverage other databases common to workflow throughout the office. These database solutions could include (1) a database containing the data tables that store core streams monitoring project data and (2) a database(s) containing other data relevant to operational and project needs, integrated through a user interface. This configuration

allows for improvements and revisions to the database user application without altering the actual data structure or any of the records in the back-end database data tables.

The database containing the core streams-monitoring data has indicators to represent where data are in the data life cycle. The database should also have an automated log file that tracks the users who access it, as well as any modifications they might make to either the database structure or data. The database should have metadata or documentation that articulates the data dictionary, management of the database, and versioning procedures.

The user interface should contain forms for data entry and modification; queries for verification, validation, and data export; and code for creating custom features designed to maintain efficient workflow. The application should have documentation that articulates procedures for management and versioning, as well as easy-to-understand user instructions.

The database created by the authors of this protocol is based on the NPS Natural Resource Database Template (a set of relational database tables in Microsoft Access recommended by the NPS I&M program for these types of databases). The design includes standardized core tables for elements (such as Locations and Events) that are common to most monitoring datasets, as well as a field data table that can be duplicated and customized to meet individual project data requirements.

The project leader should have a thorough understanding of the project database structure and procedures for using the application. Any and all documentation requested by the project lead, staff, or partners should be made available in read-only format.

5.3 Data-entry procedures

Streams-monitoring sampling data are acquired as specified in the protocol SOPs, using three different methods: (1) data are entered directly into the project database on

ruggedized field laptop computers, (2) data are manually recorded on paper datasheets, or (3) data are downloaded from handheld or automated sensors.

Transcription errors are minimized and efficiency is increased when data are entered directly into the digital database. Data collected on field computers are subject to a series of backups in the field and office to ensure that adequate data redundancy is achieved. In the event of equipment failure in the field, paper datasheets are completed to avoid lost information. To facilitate accuracy, QA/QC mechanisms are built into the database to eliminate as many potential data-entry errors as possible.

Digital data-entry forms serve as the user's portal into the database. Location and sampling-event information are entered first. Then, associated hydrologic, aquatic, or riparian data may be entered into the targeted tables. Where appropriate, picklists limit values entered into a field to ensure that only valid names or measures are used.

Data recorded on paper datasheets must be entered into the digital database as soon as possible following collection (beginning data entry after the field season ends is not acceptable). Keeping current with data entry facilitates finding and correcting errors while the information is still fresh in the minds of the field crew.

Data downloaded from electronic sensors are processed as specified in the appropriate SOP.

5.4 Data certification process

Data verification is the process of checking the accuracy of digital data against copies of original paper datasheets. This critical but time-consuming step has been largely eliminated through the use of field computers for direct data entry. However, data recorded on and entered from paper datasheets will still need to be verified.

Data validation is the process of reviewing digital data for range and logic errors. Although some validation features, such as range limits, are built into the database itself via data-entry forms (see above) and queries,

the project leader or another person familiar with the data must further review the dataset for these types of errors. For data that were directly input into the database in the field, a paper version of each completed data form should be printed for archival purposes after data validation has been completed. Spatial data are validated according to the procedures specified in SOP #5, using the latest version of ArcGIS software (ESRI, Inc.).

Data certification is the process of ensuring that the dataset (i.e., the database containing all the records for that year) has been verified and validated for accuracy, is complete, and is fully documented. Data certification is completed annually for all tabular and spatial data and photographs. This process should be documented by the project leader in order to notify the data manager that data are ready for archiving and storage. After the dataset is certified, it can be used in analysis and reporting.

5.5 Metadata procedures

Any data produced by the streams monitoring project should have accompanying metadata, especially if any data are going to be distributed. Metadata help users to locate and use their own data resources and those of others. Metadata also help to preserve data history, allow the data life cycle to be effectively managed, identify the effective and administrative limits of data use, and instill data accountability by requiring producers to state what they do and do not know about the dataset.

At the most basic level, metadata ensure the longevity and usability of the dataset. When personnel changes cause an organization to lose institutional knowledge, undocumented data can lose their value. Subsequent employees may be left with minimal understanding of the contents and uses of a digital database and may be unable to trust the results generated from those data. Also, lack of knowledge about data produced by other organizations can lead to duplication of effort. For these reasons, in the long term, metadata are well worth the investment of time and resources required to generate them (FDGC 2011; <http://www.fgdc.gov/metadata/>).

For geographic metadata, refer to the “SODN Metadata Development Guidelines” (Angell 2005). All database objects (e.g., tables, fields) have been defined and documented in a data dictionary and/or in Section 5 of a Federal Geographic Data Committee (FGDC)-compliant metadata file. Both spatial and non-spatial metadata records are uploaded to the NPS Natural Resource Information Portal, where they are available to the public. All metadata records are updated as needed whenever additional data are collected and added to the data set (Angell 2005).

5.6 Product integration and distribution

Multiple products will be generated from this dataset: field summaries, data summaries, status reports, and synthesis-and-trend reports. All data should be assessed for sensitive content or proprietary purposes. All data, metadata, and reports judged to be non-sensitive and non-proprietary should be made available to all interested parties. Other datasets, including those containing sensitive data, may be requested in writing from the data steward. Sensitive data are released only with a signed confidentiality agreement. Each network or organization is responsible for ensuring that data are stored in the appropriate location and format, and are obtainable by all person(s) interested and authorized to access the dataset(s).

5.7 Data maintenance and archiving

The project databases are archived on a secure server with regularly scheduled backups. To ensure data compatibility with other existing or newly developed software programs, each database table should be exported to an ASCII file. These ASCII files are stored on a secure server drive. All archived files are designated as read-only.

Before making revisions to streams data, the application, or the database schema, a copy of the current version must be stored to facilitate tracking of changes over time. Changes made to either the dataset, database, or application will be documented and tracked in the metadata. All revisions will be done in a timely manner to minimize disruptions to project operations, and reviewed for clarity and technical soundness. Frequent users of the data will be notified of the updated version by data management staff.

After data have been certified and archived, they may be edited only under the following conditions:

1. Changes must improve or update the data while maintaining data integrity.
2. All changes must be documented in the database change/version log.
3. Users must be prepared to recover from mistakes made during editing.

Printed data records must not be altered. Rather, they are reconciled to the database through the use of the edit table. Any editing of archived data must be accomplished jointly by the project leader and data manager.

6 Analysis and Reporting

Frequent updates and reporting are important for assessing the status and trends of streams. Network staff provide sampling field summaries after each sampling event, annual hydrologic reports for each park, status reports every five years, and trend reports every 10 years.

6.1 Analysis and quality assurance

6.1.1 Analysis

SODN/SOPN will use the most proven and efficacious methods to analyze the data collected for each vital sign. Current methods are based on those used by the USGS for water quantity (e.g., Sauer 2002; Smith et al. 2010) and water quality (Helsel and Hirsch 2002). However, the field of analysis of aquatic and riparian data is constantly evolving and changing. The use of generalized linear modeling and other mixed models has recently proven to be useful in analysis of complex data such as that gathered by this monitoring program (McCullagh and Nelder 1989; Zuur et al. 2009).

This protocol will conduct trend analysis on selected parameters (see Chapter 2) from the following monitoring modules: water quantity, riparian vegetation, and water quality.

6.1.1.1 Water quantity

We will detect trend in annual and hydrologic-season baseflow stream discharge data. The raw data will come from USGS stream-flow gauge stations. We use R code (Ryberg and Vecchia 2012) based on the USGS HYSEP program (Sloto and Crouse 1996) to separate baseflow from higher-flow data. We then use the USGS R package EGRET (Hirsch and De Cicco 2015) to organize the data and the R-ESTREND R package (<https://github.com/USGS-R/restrend/>) to conduct seasonally adjusted Kendall-Tau tests (based on Schertz et al. 1991) on the streamflow data.

Particular methods or statistical packages may be updated as methods are refined and updates.

6.1.1.2 Riparian vegetation

The methods for determining trend in riparian vegetation include, but are not limited to, parametric and non-parametric tests. These range from parametric tests, such as the student-t test, to non-parametric tests, such as Wilcoxon rank sum, to more complex trend analyses, such as generalized mixed models. Ordinal techniques will be used to examine community structure and changes to these structures over time.

6.1.1.3 Water quality

Water quality trend analysis will use the seasonal Kendall test for monotonic trends and seasonal rank sum test for step trends.

6.1.2 Quality assurance and quality control

The SODN/SOPN stream monitoring program has drafted a quality assurance project plan (QAPP) that evaluates and communicates the quality assurance/quality control (QA/QC) procedures undertaken for the program. This QAPP will accommodate national and state requirements as needed, and be reviewed annually to accommodate any changes in programmatic, local, state, or federal requirements. An annual report will concisely summarize the results of these efforts.

For the water quality module, this protocol will adhere to USGS quality assurance methodology as closely as possible (Turnipseed and Sauer 2010). At USGS stream gauge sites (see Section 4.1.1.2), we will defer to the QA/QC methods used by the agency and staff that manage and service the gauges. In these cases, we will use the published products and data from these gauge stations. At stream gauge sites managed by SODN or SOPN, we will use QA/QC methods found in Mastin (2016).

For all other modules, methods for quality-assurance assessment of field data, data management, and analysis will be explained and provided in the streams-monitoring QAPP. Quality assurance will focus on field audits

by supervisors on field crews, data assessment, and data management, in accordance with the SODN data management plan (Angell 2005) and SOPN data management plan (Sosinski 2008).

6.2 Reporting

6.2.1 Field summaries

Upon completion of each site visit, SODN staff submit a short, non-technical field summary to the corresponding park's chief of natural resources and superintendent. These summaries are produced under the leadership of the ecologist and lead biological science technician. The purpose of these qualitative summaries is to quickly highlight observed resources of management concern and general ecological observations of interest noted by the crew. Examples might include noting exceedances of water quality standards, observing a previously undiscovered exotic plant infestation, or discovering evidence of a new social trail or illegal border crossing. Field summaries are intended to quickly route important, interesting observations to park staff without the delay of producing an annual status report based on verified data and quantitative analysis and interpretation. An example field summary can be found in Appendix C.

6.2.2 Annual hydrological reports

Park-specific hydrological reports for the previous water year are submitted to staff at each park. These reports are prepared by network staff under the leadership of the program manager and project lead and follow NPS Natural Resource Publication Management guidelines. The purpose of these reports is to succinctly communicate and publish the data collected at each park unit during each water year in a timely manner. Examples can be found at <https://www.nps.gov/im/sodn/streams.htm>.

6.2.3 Status reports and analyses

Network staff prepare park-specific status reports under the leadership of the program manager and project lead every five years—typically, during years when channel morphology and riparian vegetation are sampled.

The purposes of these quantitative reports are to (1) describe the current conditions (status) of the riparian area, water quality, and discharge using standard univariate and multivariate descriptive statistics, graphical techniques, and (where appropriate) conceptual diagrams; (2) interpret these conditions in the context of other resources of interest and management objectives; and (3) explain the sampling techniques, effort, and level of certainty upon which the data and interpretations are based.

The corresponding park's representatives on the SODN and SOPN board of directors and technical committee will review draft status reports for sensitive data and policy implications, as per NPS Director's Order #66. If any reports are deemed to include restricted data, only NPS personnel will have access to full reports. The public will have access to versions without the restricted content. Few reports are expected to contain restricted data. Pending review by the aforementioned park representatives, final status reports will be submitted for publication in the NPS Natural Resource Report Series. An example report can be found at <https://irma.nps.gov/DataStore/Reference/Profile/2218584>.

6.2.4 Synthesis and trends reports

Every 10 years, the SODN/SOPN stream monitoring project will produce synthesis and trends reports. The program managers will direct the production of this report, which will involve network staff as well as external subject-matter experts, when appropriate, based on monitoring data. The purposes of this report will be to (1) describe trends (if any) in stream vital signs using univariate and multivariate time series analytical techniques, (2) use modeling and other data-exploration techniques to evaluate potential explanatory variables and covariates over broad thematic and spatial scales, and (3) synthesize this wide-ranging information to explore patterns and better understand processes of stream and wash dynamics. Status information for that year will also be presented in the synthesis and trends report.

Draft synthesis and trends reports will be reviewed by the relevant park managers. In addition, these reports will undergo an exter-

nal science review, to be coordinated by the SODN/SOPN program manager and IMR regional coordinator. The purposes of this review will be to (1) ensure that the report and its conclusions are founded on sound science and (2) encourage additional input on candidate explanations and approaches for additional synthesis and suggest high-priority research. Upon successful completion of all reviews, final synthesis reports will be submitted for publication in the NPS Natural Resource Report Series and/or peer-reviewed scientific publications.

6.2.5 Additional communication products

All reports described in Sections 6.2.2–6.2.4 will be posted to IRMA and the appropriate network websites. To reach broader audiences—including superintendents, interpreters, and the interested public—additional communications products will be derived from those published reports, including but not limited to two-page briefs and social media posts.

7 Personnel Requirements and Training

7.1 Roles and responsibilities

This section briefly describes the duties and training required of various network and cooperators staff working on SODN/SOPN streams monitoring.

7.1.1 *Project coordination and oversight*

The SODN ecologist organizes and oversees the perennial streams monitoring effort and reports to the SODN program manager. The ecologist must have in-depth knowledge of this protocol and associated SOPs in order to successfully plan and execute field work and complete analysis and reporting requirements appropriately. The ecologist coordinates the project, trains the biological science technicians, and leads some of the field-data collection.

7.1.2 *Data collection and entry*

Data-collection duties are divided into two sections: (1) quarterly sampling, channel morphology, and stream discharge, and (2) riparian vegetation. Each section is led by an experienced physical or biological science technician. This segregation of duties recognizes that the requisite skills and amount of time required to accomplish all the data-collection tasks of this protocol could not be completed by any single individual.

Each biological/physical science technician leads activities related to data collection and data entry, and reports to the SODN ecologist. The SODN biological/physical science technician serves as the crew leader, coordinating scheduling of field work with the ecologist and park staff. The technicians and ecologists share recruitment and training duties for the field crew.

7.1.3 *Data quality and management*

The SODN data manager leads the development of data entry and QA/QC procedures, develops and maintains relevant databases and supporting data management systems, and manages both raw and processed infor-

mation. The SODN data manager reports to the SODN program manager. The SODN data manager must have in-depth knowledge of the data types and end-user requirements for the streams protocol.

7.1.4 *Analysis and reporting*

The SODN ecologist and program manager share analysis and reporting responsibilities. The SODN biological/physical science technicians (see Section 7.2.1) are the leads for producing field summaries (see Section 6.2.1) for their respective sections of the protocol. The ecologist and program manager lead the development of annual hydrological reports, status reports, and synthesis-and-trends reports (see Sections 6.2.2–6.2.4), with support from network staff and cooperators. The writer-editor assists during the writing process and prepares the reports for publication, ensuring that they are professionally presented and meet the requirements of the Natural Resource Publication Series.

7.2 Qualifications and training

This section briefly describes qualifications and training SODN staff must have to successfully implement the streams monitoring protocol.

7.2.1 *Field data collection*

To facilitate effective, efficient data collection and equipment transport, field crews are ideally composed of at least two people: one crew leader (SODN biological or physical science technician) and one or more crew members. However, there will be times when more people are optimal (e.g., when sampling vegetation composition and density). The experience level of the crew (i.e., the ability of each member to work independently or together for each sampling activity) will, to some extent, dictate the ability of the crew to function optimally. The crew lead is responsible for assigning tasks to each person based on his/her expertise and the skills of the group as a whole.

Prior to data collection, crews must become familiar with all SOPs and park-specific materials, such as park geography and plant species lists. The ecologist provides training, and at his/her discretion, implements basic proficiency certification for staff involved with the streams protocol. Annual review of IMD required training for water quality monitoring will be conducted and any deficits addressed.

The most critical skill for each monitoring module is knowledge of the equipment employed and ability to perform the task accurately and consistently. For riparian vegetation, each crew member must be familiar with the local flora or, at least, highly competent at utilizing botanical keys to identify plants to the species level. Knowledge of herbarium-quality plant-specimen collection and preservation is also needed, as unknown species are collected for later identification.

The protocol was designed to minimize observer bias and maximize repeatability. Therefore, it is imperative that crews maintain good sampling techniques as outlined in the SOPs, and that the crew leader periodically checks for consistency among observers. Training and certification of workers is

contained in SOPs detailing what skills are required and at what level of proficiency for each module.

7.2.2 Safety and qualifications

The SODN physical/biological science technician (crew leader) is responsible for ensuring that all crew members read and understand the SODN safety plan prior to the field season. Additional, park-specific safety plans must be strictly followed to ensure compliance with park guidelines and safety among crew members. Wilderness or basic first-aid training is not required for all crew members, but is recommended. At least one person, preferably the crew leader, should be currently certified in first-responder care and cardiopulmonary resuscitation (CPR). All crew members must be proficient with the use and etiquette of park radios, as this is often the only reliable form of communication between the field crew and park staff. Each crew member is responsible for safeguarding him/herself at all times. At a minimum, each member should receive training on how to adequately prevent environmental illness and injury, as well as on team safety awareness.

tion and smooth organization between the field, data management, and data analysis and reporting staff. Any general operational needs (e.g., revisions to SOPs, equipment repairs, updates to park species lists) identified during the close-out are addressed during a training and field-season preparation phase that occurs in September.

The bulk of the field workload is borne by the SODN lead hydrological and biological technicians and interns, with support from other SODN staff. Data entry and basic QA/QC procedures are incorporated into field data collection through the use of field laptops. These efforts are supported by planned days in the office and other facilities (e.g., herbarium to identify unknown specimens) to resolve any data-management issues. To ensure that the overall program is staying on track, brief “pace” meetings with field, data management, and analysis and reporting staff are held quarterly (see Figure 8-1). During each quarter, data collected in each module are verified and validated by the lead technician and ecologist.

During the first week of October, the previous water year’s database status is confirmed as complete (i.e., all data are verified and validated). Data certification is completed under the leadership of the SODN data manager and ecologist. A data close-out meeting occurs at the end of October to make certain that the data processing is complete, queries are functional, and the final data matrices and spatial layers are ready for analysis.

The SODN aquatic ecologist leads analysis and reporting efforts, as described in Section 6-2. Any data that may be considered sensitive or contain policy implications are addressed in accordance with the corresponding director’s orders and NPS policy. The SODN aquatic ecologist leads an evaluation and close-out meeting (in May) to identify any future protocol changes and document the project year.

8.1.2 Module workflow cycle

The work cycle for each module begins at the protocol close out/review meeting. Any major purchases, updates or modifications to the schedule are addressed at this meeting.

From mid-June to mid-July, training activities are undertaken, major purchases are made, and necessary modifications to SOPs and any other documents are completed.

All field staff, including long-term SODN positions, seasonal staff, and volunteers/interns, complete training in each module as appropriate. These training and field season preparation tasks are led by the SODN lead technicians and the SODN ecologist.

Before each sampling event, there is a pre-field work meeting to ensure that all workers are trained, the sampling equipment is ready, data recording equipment is ready (i.e., database is loaded on field computer and is functioning); and SOPs and field datasheets are updated and available. To facilitate accountability, and to serve as an important QA/QC step, the checklist associated with this SOP is completed, signed by the lead technician, and filed in the streams protocol project file.

Field-data collection occurs year-round. However, some tasks are scheduled to standardize and optimize data collection (see Table 8-1). For instance, surveying for the channel morphology module is typically scheduled in the winter, when most riparian trees and shrubs do not have leaves.

8.1.2.1 Module 1: Water quantity

This module pertains to the data mining, field work, data management, analysis, and reporting of discrete and continuous stream stage and discharge measurements. Field work at NPS stream gauging stations is typically conducted during quarterly sampling. To increase efficiency, every attempt is made to coordinate visits with other monitoring activities. Work includes conducting a stream-discharge measurement, downloading data from datalogging equipment, and assessing status of equipment relative to the level of wear and maintenance needs. Annual field QA/QC procedures and any repairs take place once each year, during the quarterly visits. Streamflow data from other sources, primarily the USGS and state environmental agencies, are downloaded quarterly to the project database.

8.1.2.2 Module 2: Channel morphology Channel morphology fieldwork is conducted

at each stream segment every five years, or sooner if contingency requirements are met (e.g., fire, large flood). Work in this module—primarily, surveying stream segment cross-sections and longitudinal profiles, collecting bed particle size assessments, and conducting rapid ecological assessments across the stream segment—is conducted during the same water year when riparian vegetation is sampled. It usually takes a crew of two workers 3–4 weeks to complete field work, data management, and field summary reporting—depending on the number of segments, the segment size, and complexity of the geography. This work is undertaken in the winter months, or when the riparian vegetation does not have leaves to facilitate taking measurements.

8.1.2.3 Module 3: Riparian vegetation

Riparian vegetation fieldwork is conducted at each stream segment every five years, or sooner if contingency requirements are met (e.g., fire, large flood). This fieldwork is typically done during the same water year when the channel morphology module is conducted. Sampling of riparian vegetation is usually done in May–June. It takes a crew of four workers 2–4 weeks to complete field work, data management, and field summary reporting depending on the number of tasks, and complexity of the flora.

8.1.2.4 Module 4: Water quality

This module pertains to the data mining, field work, data management, analysis, and reporting of discrete and continuous water quality measurements. Field work at NPS stream index sites are typically conducted during quarterly sampling visits. Work includes conducting discrete core water quality measurements, collecting samples for analysis by contract labs and network staff, downloading data from datalogging equipment, and assessing status of equipment relative to level of wear and maintenance needs. Annual field QA/QC procedures and any necessary repairs take place once each year, during the quarterly visits. Water quality data from other sources, primarily the USGS and state environmental agencies, are downloaded quarterly to the project database.

8.1.2.5 Module 5: Benthic macroinvertebrates

To increase efficiency, benthic macroinvertebrates are sampled during state index periods coterminous with quarterly sampling events. Work includes collecting benthic macroinvertebrates, assessing bed particle size, mapping stream-reach microhabitats, and conducting rapid ecological assessments of the sample reach. This work typically takes 1–2 days in the field. Identification and enumeration of benthic macroinvertebrate taxa by the contract lab can take up to a year.

8.1.2.6 Module 6: Fish and other wildlife

SODN works with state and federal partner agencies to collect data on fish from both inside park units and from other sites in the region for comparison and spatial analysis. This work typically occurs during state-mandated sampling index periods, and is conducted by personnel with the correct training, gear, and identification skills. Care must be taken to do the least amount of disturbance to the fish during sampling due to the high incidence of rare fish in park streams.

8.1.3 Data management

Data management is vitally important to the success of this protocol. Procedures for prompt, appropriate processing of information after each sampling event are detailed in the SOP for each module. These SOPs dictate the flow of data from the various datasheets and field computers into the streams database and other files (e.g., AQUARIUS and EQuIS external databases). In general, data are entered into the streams database in the field, or as soon as possible after collection. Data for each module are verified and certified approximately one month after sampling has been completed, as dictated in the SOP for each module. A “field summary” report is generated for each visit and sent to park superintendents, natural resource managers, and other applicable personnel approximately one month after sampling has been completed. It is imperative that park managers know the results of sampling as soon as possible to respond to any information that needs prompt action (e.g., exceedances of water quality standards).

Table 8-1. Partial list of equipment required for streams protocol.

Type	Item(s)
General equipment	Ruggedized laptop (e.g., Toughbook PC) Laptop batteries (4) External hard-drive for backup GPS (2), preferably integrated handheld mapping units with GPS (e.g., Trimble GeoXT). Digital camera (10-megapixel minimum resolution) (2) Safety equipment includes, but is not limited to: waders, personal flotation devices, first-aid kits, snake chaps, and communication systems, such as park radios and cell phones.
Quarterly sampling	Water quantity (discrete) Flow Tracker or pygmy meter and handset & stadia rod (1) Transect tape Core water quality parameters (discrete) Handheld multiparameter water quality meter (e.g., YSI 556) Core water quality parameters (continuous) Multiparameter sonde (2) e.g., YSI 600XLM Biological condition Field microbiological lab including portable incubator (e.g., IDEXX quantitrays system) Small temperature datalogger and reader (e.g., Onset temperature TidBit) Primary nutrients, pollutant metals Collection decanter for water quality "bottle" samples 45-nm filters Contract for analysis with lab
Surveying/Channel morphology	RTK-enabled GPS equipment (1 set) Total station (1) Handheld computer (1) Tripod (1) Stadia rods (3) Reflecting prisms (3) Transect tape (3)
Riparian vegetation	Transect tape (4) Chain pins
Stream discharge (continuous)	Pressure logger (e.g., soloist levellogger) and barometric pressure logger Staff gauge Crest gauge
Benthic macroinvertebrates	Kicknet Sieves Buckets Sample jars Isopropyl alcohol Transect tape Folding ruler Analysis of samples from lab

8.2 Field equipment

Field equipment needs fall into two categories: (1) general equipment used across modules, and (2) equipment unique to a particular monitoring module. A partial list of field equipment needed to implement the streams protocol is provided in Table 8-1. Additional detail on field equipment is provided in the SOPs.

8.3 Costs

8.3.1 Equipment and contracted analytical costs

This protocol requires expensive and sophisticated equipment (e.g., multiparameter sondes) that is the most effective and accurate method of collecting data and achieving project goals. Equipment costs and complexity vary greatly, and are summarized in Table 8-2, below. Annually, the equipment used in the streams protocol should be assessed as to current effectiveness, and in light of any emerging new technologies that may be cheaper or more accurate. Although the costly equipment for field data entry (ruggedized laptops and external memory backups) could be replaced solely with paper datasheets, our experience indicates that the benefits of performing electronic data entry in the field (i.e., the savings in office time and reduction in data-transcription errors) greatly outweigh the costs of using field computers. The field computers have the added advantage of providing access to reference materials, such as reference documents, detailed maps, previously collected site photographs, and GIS files. Annually, the contracts for analysis of water quality samples should be assessed for the costs and quality of the data. Project managers should be constantly looking for ways to make the program more cost-effective while still producing data of required accuracy and precision to achieve project goals.

The analysis required for water quality and benthic macroinvertebrate samples are beyond the capabilities of the program in terms of budget, facilities, and appropriately skilled personnel. The networks contract these analyses, at an annual cost of approximately \$15,000.

8.3.2 Startup costs and budget

Initial equipment costs (including a total station, survey-grade GPS equipment and several multiparameter sondes) are estimated to be approximately \$75,000. Annual operating costs are significantly less, with approximately \$2,900 per year covering consumable supplies, such as calibration solutions and factory recalibration for key equipment.

Annual personnel costs to fully implement this protocol are estimated at \$143,000 (Table 8-3). This includes personnel for field and laboratory work, data management, analysis, and reporting. Because data will be collected in the field and managed, analyzed, and reported every year, annual personnel costs should remain relatively constant.

Overall, startup costs for the streams monitoring protocol are approximately \$234,000. Costs for subsequent years are estimated at \$162,000. These initial costs do not include vehicle purchase and maintenance, computer IT assessments, training costs and database development these are understood to be available within the existing network infrastructure.

The expected lifespan of the multiparameter sondes, and surveying equipment is 10+ years with regular use and maintenance. Replacement costs should be scheduled to occur in a way that allows for meeting protocol objectives, and also recognizes budget restraints.

Table 8-2. Estimated equipment costs.

Cost type	Item	Startup	Annual cost
Equipment	General (cameras, GPS units)	\$5,000	\$500
	Module 1 (water quantity)	\$5,000	\$500
	Module 2 (channel morphology)	\$30,000	\$500
	Module 3 (riparian vegetation)	\$1,000	\$100
	Module 4 (water quality)	\$32,370	\$1,550
	Module 5 (benthic macroinvertebrates)	\$1,000	\$100
	Module 6 (fish and other wildlife)	\$500	\$100
	<i>Subtotal</i>	\$74,870	\$3,350
Laboratory analysis	Water quality	\$15,000	\$15,000
	Benthic macroinvertebrates	\$1,300	\$1,300
	<i>Subtotal</i>	\$16,300	\$16,300
Personnel	GS-7 tech (hydrology) @ 20 PP (field work)	\$40,000	\$40,000
	GS-7 tech (vegetation) @ 3 PP (field work)	\$5,000	\$5,000
	SCA intern or GS 5 (hydrology) @ 20 PP (field work)	\$30,000	\$30,000
	SCA intern (vegetation) or GS 5 @ 3 PP (field work)	\$6,000	\$6,000
	GS-11 data manager @ 2 PP (data mgmt)	\$7,000	\$7,000
	GS-11 ecologist @ 14 PP (analysis, reporting, project mgmt)	\$48,000	\$48,000
	GS-11 writer-editor @ 2 PP (reporting)	\$7,000	\$7,000
	<i>Subtotal</i>	\$143,000	\$143,000
	TOTAL	\$234,170	\$162,650

9 Revising the Protocol and Program Review

9.1 Revising the protocol

This protocol consists of a narrative and 27 separate SOPs. The protocol narrative provides the history and justification for the program and an overview of sampling methods. The protocol narrative will be revised only if major changes are made to the protocol. The SOPs, in contrast, are specific, step-by-step instructions for performing each task. They are expected to be revised more frequently than the protocol narrative.

Careful documentation of such revisions, including an archive of previous versions, is essential for maintaining consistency in data collection, analyses, and reporting. To summarize changes, the monitoring database for each component contains a field to identify the protocol version used to gather and analyze data. The steps for changing any aspect of the protocol are outlined in SOP #6. The narrative and each SOP contain a revision history log that must be completed each time the narrative or an SOP is revised. The purpose of this log is to explain why changes were made and to track document version numbers. Former and active versions of the protocol narrative and SOPs are stored on separate drives on the network server.

SODN uses a Master Version Table and Version Key number (VK#) (see SOP #6) to track which versions of the narrative and SOPs are used in each version of the monitoring protocol. The VK# is essential if project information is to be properly analyzed and interpreted.

9.2 Program review

A thorough analysis and review of the monitoring protocol will be conducted every 10 years, under the direction of the SODN program manager and regional I&M coordinator. This review will include external experts and will focus on the monitoring approach, methods, and results obtained using the protocol, in much the same manner as the initial external review required of all NPS I&M protocols. At the end of each field season, all relevant staff and cooperators will complete a less-formal review of the protocol in the context of the field season, in an effort to ensure the efficacy of the protocol. If major concerns are identified, this informal review may trigger a more-formal external review (as described above), at the discretion of the SODN.

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Appendix A. Stream Lengths

Park	Type	Sum of length (km)
ALFL	Intermittent	12.314
BEOL	Artificial_Path	4.718
BEOL	Canal/Ditch	0.047
BEOL	Intermittent	5.449
CAGR	Artificial_Path	0.246
CAGR	Canal/Ditch	0.463
CHIR	Intermittent	76.043
CORO	Intermittent	52.217
FOBO	Artificial_Path	3.122
FOBO	Intermittent	12.107
FOLS	Artificial_Path	3.526
FOLS	Connector	0.251
FOLS	Intermittent	6.069
FOUN	Artificial_Path	0.035
FOUN	Intermittent	4.983
GICL	Ephemeral	3.300
GICL	Perennial	1.992
LAMR	Artificial_Path	158.471
LAMR	Connector	2.700
LAMR	Intermittent	142.371
LAMR	Perennial	18.561
LAMR	Pipeline	2.332
LYJO	Artificial_Path	0.912
LYJO	Connector	0.048
LYJO	Intermittent	8.371
MOCA	Artificial_Path	3.532
MOCA	Canal/Ditch	1.747
MOCA	Intermittent	0.538
MOCA	Perennial	1.096
ORPI	Artificial_Path	29.462
ORPI	Connector	0.216
ORPI	Intermittent	1,943.676
PECO	Artificial_Path	6.258
PECO	Intermittent	48.977
PECO	Perennial	5.613
SAGE	Artificial_Path	1.588
SAGE	Intermittent	712.174
SAND	Artificial_Path	2.508
SAND	Canal/Ditch	4.995
SAND	Intermittent	18.418
SAND	Perennial	4.806
TONT	Intermittent	11.878
TUMA	Artificial_Path	0.903
TUMA	Intermittent	2.720
TUZI	Artificial_Path	1.149

Park	Type	Sum of length (km)
TUZI	Canal/Ditch	1.382
TUZI	Canal/Ditch_Aqueduct	0.050
TUZI	Intermittent	2.930
TUZI	Perennial	0.375
WABA	Intermittent	0.009
WABA	Perennial	1.596

Appendix B. Analytical Methods

Table B-1. General parameters.

Parameter	Method	Method detection limit
Acidity	SM 2310B	2.0mg/L
Alkalinity as CaCO ₃	SM 2320B	2.0mg/L
Bicarbonate as CaCO ₃ -included in alkalinity	SM 2320B	2.0mg/L
Biological Oxygen Demand (BOD)	SM 5210B	5.0mg/L
Carbon, Total Organic	SM5310C	0.080mg/L
Carbonate as CaCO ₃	SM 2320B	1.2mg/L
Cation-Anion balance	calculated	not applicable
Chloride	300.0	0.25mg/L
Conductance, Specific @25C	SM 2510B	1 umhos/cm @ 25°C
Total cyanide	SM 4500 CN-C, E	0.017mg/L
Fluoride	SM 4500 F,C	0.020mg/L
Hardness as CaCO ₃	SM 2340C	4.0mg/L
Mercury, dissolved	245.1	0.00010mg/L
Nitrate as N, dissolved	300.0	0.0151mg/L
Nitrite as N, dissolved	300.0	0.038mg/L
Nitrogen, ammonia as N	SM4500-NH3 D	0.50mg/L
Nitrogen, total Kjeldahl	SM4500 Norg C	1.0mg/L
Nitrogen, total	calculated	1.7mg/L
pH	SM 4500 H B	1.68 pH Units
Sulfate	300.0	0.20mg/L
Residue, Non-Filterable (TSS)	SM 2540D	0.010mg/L
TDS Residue on evap. @ 180°C, water, filtered	SM 2540C	1.0mg/L
TDS	calculated	–
TDS	ratio - measured/calculated	–

**Table B-2. ICP Metals with Digestion
Dissolved Metals (Method 200.7,
MDL/RL mg/L).**

Parameter	Method detection limit
Boron	0.020 / 0.050
Cadmium	0.0020 / 0.0050
Iron	0.015 / 0.040
Magnesium	0.012 / 0.020
Phosphorus	0.020 / 0.040
Potassium	0.37 / 0.50
Silica SiO ₂	0.028 / 0.11
Sodium	0.19 / 0.50

**Table B-3. ICP Metals with Digestion
Total Metals (Method 200.7, MDL/RL
mg/L).**

Parameter	Method detection limit
Boron	0.020 / 0.050
Calcium	0.050 / 0.10
Iron	0.015 / 0.040
Magnesium	0.012 / 0.020
Phosphorus	0.020 / 0.040
Potassium	0.37 / 0.50
Silica SiO ₂	0.028 / 0.11
Sodium	0.19 / 0.50

**Table B-4. ICPMS Metals with Digestion
Dissolved Metals (Method 200.8, MDL/
RL µg/L).**

Parameter	Method detection limit
Aluminum	8.5 / 10.0
Antimony	0.30 / 2.0
Arsenic	0.90 / 1.0
Barium	0.30 / 1.0
Beryllium	0.10 / 0.50
Cadmium	0.10 / 1.0
Chromium	0.90 / 2.0
Copper	0.50 / 1.0
Lead	0.20 / 1.0
Manganese	0.70 / 1.0
Molybdenum	0.20 / 2.0
Nickel	0.50 / 2.0
Selenium	0.50 / 1.0
Silver	0.10 / 1.0
Thallium	0.20 / 1.0
Uranium	0.20 / 1.0
Zinc	4.0 / 5.0

Appendix C. Example Field Summary Report

Sonoran Desert Network Streams Protocol *Riparian Vegetation Component*



Field Summary Report
Gila Cliff Dwellings National Monument
1/2/2013

Purpose: To briefly summarize the 2012 field season of riparian vegetation monitoring at Gila Cliff Dwellings National Monument.

Contacts: Please direct any questions about our vegetation monitoring program to project manager Sarah Studd, at (520) 343-8845; sarah_studd@nps.gov.
Questions about Streams Monitoring can be directed to project manager Evan Gwilliam, at (520) 403-3055; evan_gwilliam@nps.gov

Vital signs and other parameters sampled during this visit

- Vegetation cover: measured along 20-m transects that lie perpendicular to the cross-sections. Species-level estimates of cover were recorded within three height strata: 0–0.5 m, 0.5–2 m, and >2 m.
- Aquatic macrophyte frequency: plants growing within the river were recorded
- Species/life form frequency: all species occurring within 2 m of transects were recorded
- Tree density
- Seedling/Sapling density
- Diameter at breast height (DBH) for trees
- Height and DBH for legacy trees (DBH >50cm)

Sampling highlights/notes

- This field effort represents the second year of sampling at the monument. The survey area encompasses the entire stretch of the Gila River within the main unit of the monument and east to the Upper Scorpion Campground (Appendix A).
- We resampled a total of 55 zone transects (inland from the river edge) and 22 greenline transects (adjacent to river's edge) this calendar year, along all 11 cross-sections.
- We resampled a total of 17 density plots this calendar year, one on each side of the Gila River, for all cross-sections with adequate room to place a plot.
- We documented a total of 87 tree-size (>15-cm DBH) *Populus angustifolia* (narrowleaf cottonwood), of which 22 were dead and 65 were dead and re-sprouting (for the “dead and re-sprouting” individuals, pre-fire aboveground biomass was dead and re-sprouts were emanating from the base of the individual).

- We detected exotic species on 40 zone transects (80%) and 11 greenline transects (50%). The most common exotics included *Verbascum thapsus* (common mullein), on 47 transects, *Melilotus alba* (white sweetclover) on 30 transects, and *Polygonum convolvulus* (black bindweed) on 18 transects.

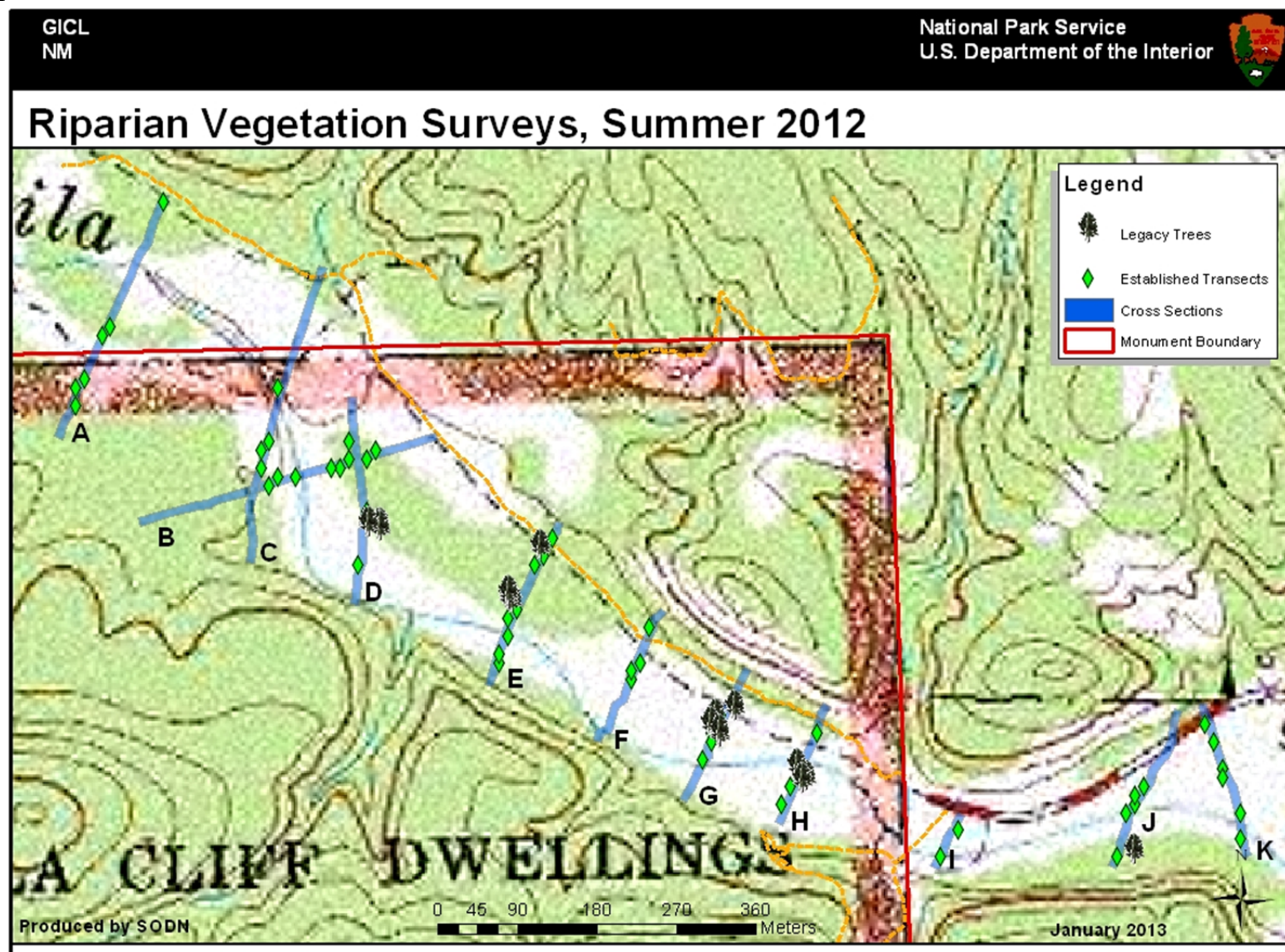
What's ahead?

By the end of 2013, the data collected during the first two field seasons (2011 and 2012) will be analyzed and an annual summary report completed. This report, to be published in the NPS Natural Resource Technical Report Series, will review the overall design and present plot data.

In 2013, depending on available resources, we may resample all cross-sections for a third consecutive year of post-fire monitoring.

In 2015, we will resample all cross-sections as part of our five-year sampling cycle.

Appendix A: Cross-section and transect locations.



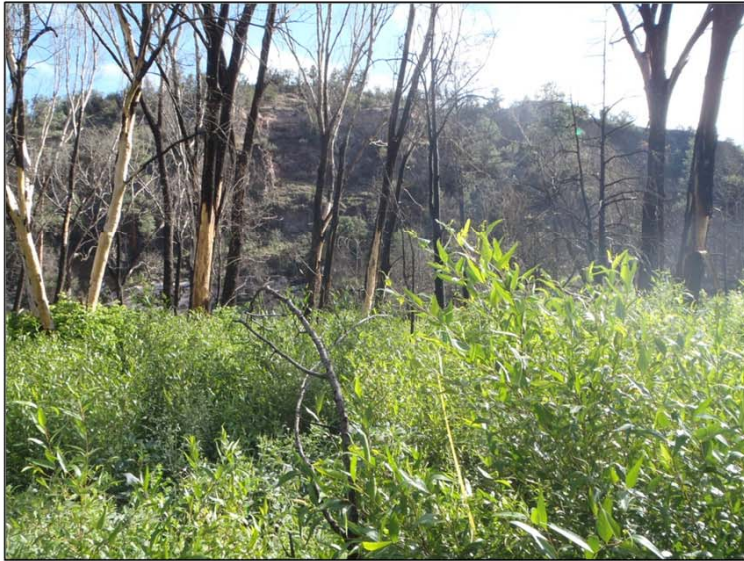


Figure 1. Cross-section G, river right density plot showing re-sprouting *Populus angustifolia* (narrowleaf cottonwood).



Figure 2. Greenline of cross-section J, river right, showing *Verbascum thapsus* (common mullein) and *Melilotus alba* (white sweetclover)

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