



Springs Monitoring Protocol Implementation Plan for Park Units in the Southern Colorado Plateau Network

Natural Resource Report NPS/SCPN/NRR—2018/1771



ON THE COVER

Spring-fed pools in the Abo Unit of Salinas Pueblo Missions National Monument
Photography by: Southern Colorado Plateau Network, NPS

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Dustin W. Perkins^{1,2}

Rebecca Weissinger²

Mary Moran²

Steve Monroe¹

Helen Thomas²

Lee McCoy¹

Ellen Soles¹

¹National Park Service
Southern Colorado Plateau Network
2255 N. Gemini Drive
Flagstaff, AZ 86001

²National Park Service
Northern Colorado Plateau Network
P.O. Box 848
Moab, UT 84532

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1 Introduction and Summary

In semi-arid regions, such as the Colorado Plateau, springs and seeps occupy a tiny fraction of the overall landscape, yet they support disproportionately high levels of productivity (Oberlin et al. 1999; Perla and Stevens 2008), biodiversity, and endemism (Welsh and Toft 1981; Erman 2002; Hershler and Sada 2002; Sada et al. 2005; Spence 2008). At broader spatial scales, springs play key roles in arid ecosystems by providing refugia for migratory birds (Skagen et al. 1998) and critical habitat for reptiles and amphibians, and also by serving as the primary source of water for more extensive aquatic and riparian habitats. A meta-analysis estimated that over 60% of species found in arid region riparian areas are not found in adjacent upland habitats (Sabo et al. 2005).

Springs in arid and semi-arid regions are also often focal points of human activity with widespread human impacts (Shepard 1993; Hubbs 1995). Surface and groundwater diversions, livestock grazing, and recreation are disproportionately high in these areas, and represent primary threats to spring ecosystems. An inventory of 103 springs on the Arizona Strip found that over 90% had some type of development for human, livestock, or game use (Grand Canyon Wildlands Council 2002). Another study of 505 springs in northern Nevada found that 85% were disturbed by livestock and diversions, and only 5% of the springs were unaffected by human disturbances (Sada et al. 1992).

Because of their importance for wildlife and ecosystems on the Colorado Plateau, and because of the effects that human use has had, and continues to have on these rare resources, spring ecosystems were identified as ecosystems of concern by the Southern Colorado Plateau Network (SCPN), and scientists of network parks. This protocol implementation plan (PIP) describes the procedures for implementing the Springs Monitoring Protocol for Park Units in the Northern Colorado Plateau Network (NCPN) (Weissinger et al. 2017) as it relates to springs selected for monitoring in SCPN park units. It also

incorporates sections of the Riparian Monitoring of Wadeable Streams Protocol for Park Units in the Northern Colorado Plateau Network (Weissinger et al. 2018) and Big Rivers Monitoring Protocol for Park Units in the Northern Colorado Plateau Network (Perkins et al. 2018).

Weissinger et al. (2017) defines springs as groundwater-dependent ecosystems with measurable flow or stage, and defines seeps as groundwater dependent ecosystems without measurable flow or stage. The essential driver of spring ecosystems is the source of the water and the geologic structure that brings it to the surface (Bryan 1919). Springs and seeps vary tremendously in their surface expression, with the topographic setting of the spring emergence affecting available habitat and environmental conditions, resulting in a rich array of possible spring types. Figure 1 presents a site-specific conceptual model of spring ecosystems typical of the Colorado Plateau. Springer and Stevens (2009) developed a classification system for spring types based in part on work on the Colorado Plateau (Table 1).

A wide variety of spring types are found within SCPN park units, including hanging gardens (seep lines along contact and bedding planes in sandstone), pools (limnocrene), channelized flow (rheocrene), flow gushes from a cliff wall (gushette), and low-gradient (helocrene) and high-gradient (hillslope) springs with diffuse, unfocused flow. This PIP is designed for sampling hanging gardens, as well as conducting initial site visits to other spring types while additional procedures are being developed for sampling these types.

Hanging gardens are the most numerous spring type of interest to SCPN parks at this time. In addition to the hanging gardens at Glen Canyon National Recreation Area (GLCA), Canyon de Chelly National Monument (CACH), and Navajo National Monument (NAVA), other springs of interest in SCPN parks include:

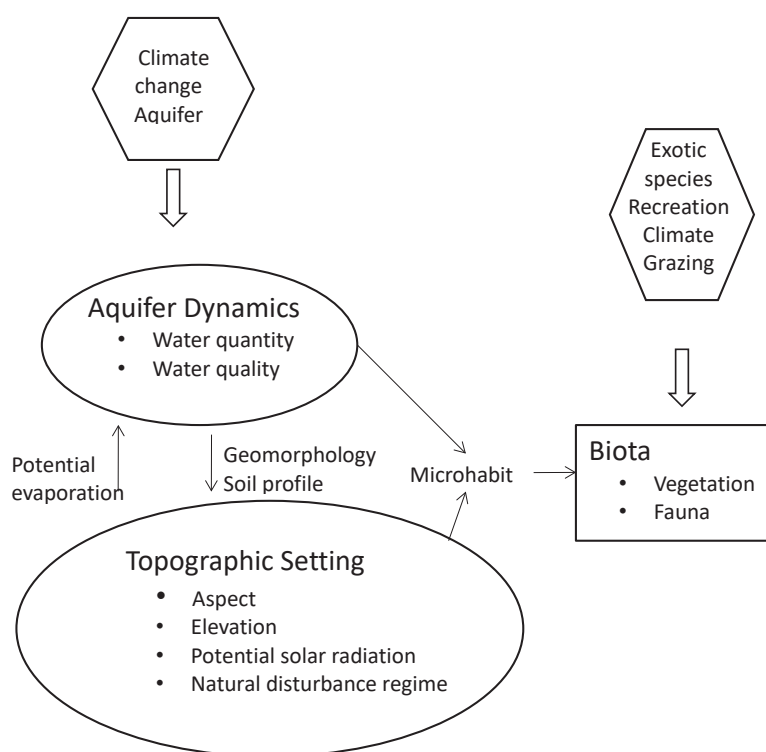


Figure 1. A general conceptual model of spring ecosystems of the Colorado Plateau. Ovals represent major drivers of ecosystem change and variability. The rectangle represents important structural components. Arrows describe functional relationships among system components. Hexagons represent significant potential stressors. The model is constrained by state factors including global climate, geology, time, and potential biota. Modified from Stevens and Springer (2004).

- a helocrene spring at Yucca House National Monument (YUHO)
- rheocrene springs at CACH
- a hillslope spring at Wupatki National Monument (WUPA)

SCPN expects that parks will select additional springs for monitoring. Table 2 presents high priority springs proposed for monitoring as well as medium and low priority springs that could be implemented in the future. Final decisions as to which springs will be monitored by SCPN will be made with the affected parks in the fall of 2018. The rationale to be used in selecting sites for monitoring is explained in Appendix A. The network recognizes that additional methods will need to be developed for the spring types selected. These methods will be addressed in future versions of this implementation plan. In the interim, the Standard Operating Procedures (SOP) pertaining to spring site characterization (SOP #3), vegetation characterizations (SOP #4), water quality (SOP #5), and site condition and photos (SOP #6) will be implemented for non-hanging garden springs during reconnaissance trips which will guide the development of new

Table 1. Definitions of spring types (Source: Springer, A. E., and L. E. Stevens. 2009. Spheres of discharge of springs. *Hydrogeology* 17:83–93.)

Spring Type	Definition
Cave	Emergence in a cave in mature to extreme karst with sufficiently large conduits
Exposure	Cave, rock shelter fractures, or sinkholes where an unconfined aquifer is exposed near the land surface
Fountain	Artesian fountain with pressurized CO ₂ in a confined aquifer
Geyser	Explosive flow of hot water from confined aquifer
Gushet	Discrete source flow gushes from a cliff wall of a perched, unconfined aquifer
Hanging garden	Dripping flow emerges, usually horizontally, along a geologic contact along a cliff wall of a perched, unconfined aquifer
Helocrene	Emerges from low gradient wetlands; often indistinct, or multiple sources seeping from shallow, unconfined aquifers
Hillslope	Emerges from confined or unconfined aquifers on a hillslope (30–60° slope); often indistinct or multiple sources
Hypocrene	A buried spring where flow does not reach the surface, typically due to very low discharge and high evaporation or transpiration
Limnocrene	Emergence of confined or unconfined aquifers in pool(s)
Mound	Emerges from a mineralized mound, frequently at magmatic or fault systems
Rheocrene	Flowing spring, emerges into one or more stream channels

Table 2. Springs selected for monitoring in SCPN parks, the spring category (sentinel site or random sample of hanging gardens), and spring type. High priority springs will be implemented first. Click [here](#) for a 508 accessible version of this table.

Park	Spring	Spring Category	Spring Type	Comment
High Priority Springs				
CACH	Wild Cherry Cattail	Sentinel	Rheocrene	Final selection will be made in October 2018.
	Tsaile	Sentinel	Rheocrene	
	Many Cherry	Random sample	Hanging Garden	
	Twin Trail Canyon	Sentinel	Rheocrene	
	Bare Rock	Random sample	Hanging Garden	
GLCA	Waterpocket Fold	Random sample	Hanging Gardens	Horseshoe Canyon/East End/French Springs as sentinel springs. Waterpocket Fold Navajo Sandstone Aquifer (higher priority) or the Wilson Mesa/Gray Mesa Aquifer (lower priority) as random sample of hanging gardens.
	Horseshoe Canyon	Sentinel	Hillslope	
	East End	Sentinel	Helocrene	
NAVA	Betatakin	TBD	Helocrene/Hanging Garden	Final selection will be made in October 2018.
WUPA	Heiser	Sentinel	Hillslope	Groundwater data collection by park, SCPN covers data management only.
YUHO	Aztec	Sentinel	Helocrene	
Medium Priority Springs – To be Implemented after High Priority Springs				
CHCU	Wijijii	Sentinel	Hanging Garden/Helocrene	Interested in vegetation and water quality.
Low Priority Springs – To be Implemented after High and Medium Priority Springs				
BAND	Frijoles	Sentinel	Rheocrene	Springs are lower than riparian.
	Apache	Sentinel	Rheocrene	
GRCA	TBD	TBD		
MEVE	Fewkes Canyon #4	Sentinel	Hanging Garden	
	Highway 160	Sentinel	Helocrene	
	Spruce Tree House	Sentinel	Hanging Garden	
	Morefield	Sentinel	Hillslope	
	Rock Canyon #2	Sentinel	Hanging Garden/Limnocrene	
PEFO	Kokopelli	Sentinel	Tinaja/Pool	Bedrock pool subject to scour events. Park is interested in water quality. Fairly stable for water quantity. Agate Bridge, Bear, and Painted Bridge are other springs.

SOPs for these springs. In addition SOP #9 (Groundwater wells) will be implemented at YUHO. The springs that will be monitored in SCPN parks fit into two general categories. The first category is sentinel springs. Sentinel monitoring sites are not randomly selected but are selected because they meet some or all of the following criteria: they are a management priority, historical data records exist for the spring, they are accessible, and it is possible to select a sampling location with a stable flow. Due to their small

number and uniqueness, there can be no inference to other springs. The second category is a random sampling of hanging gardens for which inference can occur. This is best where the park is interested in a particular canyon or other area where it is likely that springs have the same groundwater and geologic origin. In order to conduct monitoring with a random sample of hanging gardens, at least 25 springs of similar type, geology and source aquifer is needed. This is only possible at GLCA and CACH.

2 Conceptual Framework for Monitoring

Hanging gardens are a common spring type on the Colorado Plateau but are rare elsewhere in the U.S. They develop in highly permeable sandstones, along bedding planes or at the contact with a less permeable geologic layer. The presence of perennial, low-flow seeps and the absence of flooding creates a stable, localized, mesic environment. In aeolian sandstones, groundwater sapping creates protective alcoves that reduce solar radiation, temperature, and evaporation potential when compared to surrounding areas (May et al. 1995). These isolated oases are strongly differentiated from the surrounding landscape by their distinctive vegetation, and have become focal points of vascular plant endemism on the Colorado Plateau (Fowler 1995; Spence 2008). Water quantity, water quality, and vegetation composition have been selected as components to be monitored at hanging gardens and other SCPN springs (Table 3).

2.1 Water Quantity

The persistence and amount of water available at a spring site is one of the primary factors determining the extent of aquatic and riparian habitat available for biotic communities. While species richness at the spring source is often relatively low (Meffe and Marsh 1982), associated outflow and riparian areas support a disproportionately unique and diverse flora and fauna relative to their

size and in relation to surrounding desert environments (Vinson and Dinger 2008). Natural fluctuations in groundwater levels can be associated with changes in groundwater recharge, evapotranspiration, and changes in hydraulic head associated with pressure from confining geologic layers (Freeze and Cherry 1979). Springs discharging from extensive regional aquifers or groundwater systems that rely on ancient waters, tend to have relatively stable flows. However, springs from perched aquifers with short groundwater residence times may have seasonal fluctuations in water quantity based on local precipitation patterns and aquifer characteristics. Short- or long-term fluctuations in water quantity can change solute concentrations and water temperature, impacting habitat quality.

2.2 Water Quality

The chemistry of spring water is determined by the geology and length of its groundwater path (Hem 1985). Short residence times and rocks low in dissolvable materials, such as sandstone, result in spring water with low dissolved solids and high water quality. Ancient waters and waters that pass through highly dissolvable materials emerge high in dissolved solids (Freeze and Cherry 1979), which can create particularly harsh conditions for aquatic life.

Table 3. Monitoring components of this springs protocol with management issues and potential measures.

Component	Management issues informed by monitoring	Potential Metrics
Water Quantity	Decreases due to aquifer depletion and/or climate change that can affect flora and fauna and cultural resources	• median and range of stage or flow • variance of stage or flow • length of flowing channel (up to 50 m) • depth to groundwater (YUHO only)
Water Quality	Contamination or degradation shown by sudden shifts in conductance or temperature that can affect flora and fauna	• pH (median and range) • specific conductance (median and range) • temperature (median and range)
Vegetation	<i>Species composition</i> – decreases or changes due to increased recreational use, exotic species, grazing, aquifer depletion, and climate change. <i>Endemic plants</i> – decreases due to aquifer depletion or climate change	• richness by nativity • wetland status • life form cover by nativity • life form wetland: upland cover ratio

2.3 Vegetation

Plant community composition at springs is highly related to gradients of water availability and is also influenced by water quality (Strohbach et al. 2009) and soil texture (Patten et al. 2008). Euliss et al. (2004) present a conceptual model based on the prairie pothole region in the Dakotas of potential vegetation communities on a continuum of atmospheric and groundwater abundance. In a study of Great Basin springs, obligate and facultative wetland species had the highest cover in wetlands where the groundwater was within one meter of the surface. Obligate

wetland species did not occur at sites where the depth to groundwater was greater than two meters (Patten et al. 2008).

Vascular plant endemism is strongly associated with hanging gardens on the Colorado Plateau (Spence 2008). In a study of 84 hanging gardens in seven national parks on the Colorado Plateau, Fowler (1995) found that approximately 5% (12 of 201) of vascular plant species were endemic to the Colorado Plateau, and about 3.5% (7 of 201) were endemic to hanging gardens on the Colorado Plateau.

3 Measurable Objectives

The overall goal of the SCPN springs monitoring program is to determine long-term trends in hydrologic and vegetation properties of the spring environment in the context of changes in other ecological drivers, stressors, and processes. Thresholds for change in spring ecosystems on the Colorado Plateau are unknown. Specific objectives for springs monitoring include describing the status and trends of:

- Water quantity
 - Flow (discharge) or stage as applicable
 - Depth to groundwater (YUHO only)
- Water quality
 - pH
 - Specific conductance
 - Temperature
- Vegetation
 - Species composition
 - % cover
 - Endemic plant populations (hanging gardens only)

In addition, springs monitoring will include reporting the status of specific indicators of resource management interest, including:

- Presence of target exotic plants and animals
- Presence of bacteria indicating possible fecal contamination
- Presence of new or undesirable disturbances (e.g., trespass cattle, increased social trailing)

4 What's Being Measured and How?

Three vital signs are targeted for springs and seeps monitoring:

1. Water quantity
2. Water quality
3. Vegetation species composition and structure, with an emphasis on endemic plant populations at hanging gardens

Water quantity (discharge or stage) and water quality (pH, specific conductance, water temperature) are sampled at selected sites on monthly (March—November) visits at SCPN sentinel spring sites. Vegetation species cover and endemic plant counts are sampled at a random selection of hanging gardens. For all indicators, some sites are sampled annually while others are sampled on a two-year rotation.

4.1 Water Quantity

Analyses of NCPN data for springs in Arches National Park, Canyonlands National Park, Natural Bridges National Monument and Hovenweep National Monument were used to determine the power to detect trends using monthly flow and stage measurements (Weissinger and Moran 2013). Data from previously sampled springs where the sampling sites had unstable flow (e.g., alluvial wash bottoms subject to geomorphic change from flooding) were highly variable and had limited potential for detecting trends. Therefore, we have limited the scope of sampling to springs with measurable flow/stage at a stable (generally bedrock) measurement location.

Spring flow is measured as discharge (the volume of water moving down a spring per unit of time), or depth to groundwater (the height of the water surface at a location along in a groundwater well) at a permanent location within the monitoring site (SOP #5). This location should be at a place where the maximum amount of the flow is measurable. Most flow measurements are taken using a volumetric method, in which timed collections of water are taken using a plastic bag or

a container of known size. Larger springs are sampled using temporary weirs or flumes. At least five flow measurements are taken and averaged during each site visit. At helocrene springs where no surface water is present water will be measured with shallow groundwater piezometers (SOP #8) and surveyed annually (SOP #9).

4.2 Water Quality.

Changes in water quality core parameters in springs can signal changes in water chemistry. Water chemistry at springs is primarily tied to the geologic path (water/rock interactions) and travel time of the spring aquifer and surface water–groundwater interactions (Hem 1985). Nutrients in surface water were not found to be highly related to disturbance categories at sandstone springs on the Colorado Plateau (Weissinger et al. 2012). Because laboratory analysis of water chemistry samples is relatively costly, we will monitor good indicators of water quality: specific conductance, pH, and water temperature, all of which are relatively inexpensive to monitor with portable probes. Changes in these parameters can be used to signal a need for additional water chemistry sampling. Water quality data are collected as near to the spring orifice as possible. When sufficient water is available, core parameters are collected using a calibrated multiparameter probe (SOP #5).

4.3 Vegetation

4.3.1 *Vegetation composition and structure*

Attempts to develop a repeatable method for monitoring vegetation composition and structure have been problematic at spring sites. A systematic, quadrat-based method was attempted during NCPN pilot sampling but was discontinued due to safety and resource concerns, particularly in the steep bedrock and colluvial slope settings often found at hanging gardens. Geomorphic surface-based methods were developed for descriptive use by Spence (2008) and

used for spring inventories during protocol development at hanging gardens throughout the Colorado Plateau (Springer et al. 2006). Vascular plant cover by species is listed for each geomorphic surface within the spring and up to 50 meters of a spring-fed run-out channel (SOP #4). Each species is classified as native/exotic, by wetland status, and by life form, as classified by the online PLANTS database (www.plants.usda.gov) and confirmed or augmented by species descriptions. While not ideal for monitoring, this technique at present is our best attempt to delineate repeatable areas for sampling. Additional methods will be developed for the high priority hillslope and helocrene springs.

4.3.2 Endemic plant counts

Using a timed search based on the spring site area, the number of endemic plant individuals by species is recorded for each hanging garden's backwall, alcove floor, and colluvial slope (SOP #7). Perennial plant species will be selected for monitoring. We will evaluate each species for robustness as a monitoring indicator after sufficient data have been collected. When staff turnover results in a new person beginning plant counts, two observers experienced with vegetation monitoring should conduct independent counts at the same sites for one season to serve as a quality check for any discrepancies between long-term observers.

4.4 Other Measurable Attributes

4.4.1 Site characterization

Site characterization includes important information for interpreting responses at springs, including geology, aspect, potential solar radiation, elevation, spring type, and geomorphology (SOPs #3 and 4). An essential component of the site characterization is a site map that delineates repeat monitoring locations for water quantity and quality measures, photopoints, and geomorphic surfaces for vegetation measures. Site characterization occurs during the growing season of the initial sampling year. Re-characterization is done at periodic intervals or when triggered by significant disturbance events, such as

fire or catastrophic flooding, or by trends of management concern, such as a 10% reduction in flow over time.

4.4.2. Habitat area

Attempts to develop a repeatable method for monitoring habitat area at NCPN springs have been unsuccessful. GPS mapping is not feasible due to the topographic setting of most springs in Arches National Park, Canyonlands National Park, Natural Bridges National Monument and Hovenweep National Monument, particularly hanging gardens. A pilot project using repeat photography and photo modeling software (PhotoModeler Scanner™) could not successfully classify vegetation and vegetated area. However, SCPN will be developing methods for hillslope and helocrene high priority springs as their more open topography will allow use of GPS. These methods will be included in future versions of this protocol implementation plan. Repeat photographs of photopoints taken during site characterization will provide a qualitative record of habitat area over time (SOP #6).

4.4.3. Site condition

A timed search of 1 minute per 5-m² of surface water, up to 30 minutes total, looking for crayfish, amphibians, and fish will be conducted at each site. Observers will walk the spring perimeter and observe signs of disturbance at the spring and within 50 meters of the spring including fecal matter from wildlife or livestock, trespass grazing, and human recreational use.

5 Sampling Design and Monitoring Schedule

5.1 Design Overview

SCPN will use two approaches to springs monitoring: (1) sentinel sites, and (2) randomly selected hanging gardens.

5.1.1 Sentinel sites

Sentinel sites are stand-alone monitoring locations that cannot be used to infer results to spring populations as a whole because they are a sample size of 1, and in some cases are the only springs in a park. However, because of their natural and cultural significance, as well as the scarcity of water on the Colorado Plateau, they are very important resources for a park and thus, are of management interest. They will be visited four times from March to November within a sample year and revisited using a panel rotation of two years of sampling followed by two years of rest. A subset of sites will be monitored yearly to track responses to unpredictable or cyclical climate events. Primary monitoring indicators at sentinel sites are water quantity and water quality. Implementation of the full suite of SOPs will only be applicable to hanging garden spring types. Additional methods and SOPs will be developed for additional spring types if they are selected.

5.1.2 Randomly sampled hanging gardens

A selection of randomly sampled hanging gardens will be used to gain an understanding of the health of hanging garden spring ecosystems at a park or in a region of a park (SOP #7). Because of the greater number of hanging gardens in some parks, a random sample can be used to make inference to larger populations. Hanging gardens will be visited once during the growing season within a sample year and revisited using a panel rotation of two years of sampling, followed by four years of rest. A subset of sites will be monitored yearly to track responses to unpredictable or cyclical climate events. The primary monitoring indicators at hanging gardens will be composition and abundance of endemic plant populations.

5.2 Spatial design description and rationale

Springs are highly complex ecosystems that vary naturally in water quantity, water quality, biological communities, topographic setting, and disturbance regimes. As a result, even springs in close physical proximity can have distinct habitat characteristics and biotic components (Malanson and Kay 1980; Spence and Henderson 1993; Erman 2002, Euliss et al. 2004; Sada et al. 2005; Meretsky 2008). The source and path of groundwater discharging at clustered spring sites is usually unknown, making it difficult to discern if local springs are fundamentally connected or functioning independently of each other. For these reasons, it is difficult to determine appropriate populations for inference in a random sample of sites, and thus a large portion of SCPN's springs monitoring effort focuses on sentinel sites.

5.2.1 Sentinel sites

Sentinel monitoring sites are selected for their management significance, the presence of historical data records, ease of access, and a stable flow-sampling location. Other criteria that were considered for site selection, but ultimately rejected, included

- hydrogeologic setting (remote and difficult access for some strata)
- water chemistry (often no data, highly correlated with hydrogeologic setting)
- source aquifer (generally unknown, current age dating methods difficult to implement at the majority of springs due to unavoidable atmospheric contamination of sample water)
- incorporating some type of spatial balance

Management concerns include recreational use, invasive plants, proposed developments outside park boundaries, climate change, and surrounding agricultural and extractive land uses. There may be some sites that are of management interest with exposed surface water but no stable flow monitoring

location; these sites will be monitored for vegetation but not flow.

5.2.2 Randomly sampled hanging gardens

To understand the population of springs and changes occurring among them, similar spring types are randomly selected for monitoring so they can be used to generalize long-term changes in condition across all systems. Hydrogeologic studies suggest that some hanging gardens have highly localized aquifers (May et al. 1995; Cudlip et al. 1999; Hurlow and Bishop 2003) making them potential candidates for a random sample. Because these sites lack a complex groundwater path and often have short groundwater-residence times, hanging gardens emerging in close proximity from the same geologic formation may react similarly to climate and precipitation events. Effects of direct anthropogenic aquifer depletion and other stressors will still need to be evaluated on a site-by-site basis.

In the site selection process, individual hanging gardens within each population were assigned a number in GIS. A random number generator (accessed at www.random.org) was then used to create a random order without replacement within each population. Each hanging garden will be sampled in the randomly generated order until the affordable sampling effort is reached. Additional power analyses will be necessary in the future to determine an appropriate sample size and sampling frequency for detecting trends in vegetation measures. Analyses should also evaluate the underlying assumption that hanging gardens can be analyzed together as a population rather than on a site-by-site basis.

5.3 Revisit design description and rationale

5.3.1 Sentinel sites

Sentinel sites are visited four times from March to November, within a sample year, and are revisited using a panel rotation of two years sampling followed by two years of rest. A subset of these sites are monitored

yearly to track responses to unpredictable or cyclical climate events.

This revisit design was based on previous work conducted at NCPN. Up to 10 years of historic monthly data collected by NCPN parks were used as a pilot dataset to document variability in flow and stage data. A power analysis indicated the selected revisit design could detect a 5% decline in median flow after six sampling seasons, while at the same time minimizing the number of samples missed due to inclement weather and access difficulties (Weissinger and Moran 2013). Water quality measures will need to be evaluated for their ability to detect trends once sufficient data have been collected.

5.3.2 Randomly sampled hanging gardens

For populations of hanging gardens, the revisit design attempts to balance the need to observe inter-annual variability with the need to maximize replication (Woodward 2004). A rotating panel design is used to increase the overall sample size (ascertain spatial variation) and provide a better estimate of the status of the population while assessing serial trends. Randomly sampled hanging gardens are sampled once per year, two years in a row, and then rested for four years (Table 4). A subset of sites, selected for their resistance to trampling, is monitored yearly to track responses to unpredictable or cyclical climate events. A preliminary analysis of NCPN pilot data used a simulated dataset to estimate whether a 10% annual change in one endemic plant population, *Aquilegia micrantha*, could be detected within 20 years of collecting data (unpublished data, code by John Tipton 8/10/13). Count data for each species must be evaluated after six years of sampling to determine the ability of the sampling design to detect long-term trends. Vegetation cover data are currently being collected using the same sampling design which can also be evaluated for its power to detect trends. Sites are added in random order, with three new sites added each year for each population. One site in each population that can easily be sampled without excessive

trampling impacts will be visited each year.

Table 4. Revisit design for Springs Monitoring in Southern Colorado Plateau parks. Number of reaches sampled each year (indicated by "X") are based on a seven-year rotating panel revisit design.

Site	Year									
	1	2	3	4	5	6	7	8	9	10
A	X	X	–	–	–	–	X	X	–	–
B	X	X	–	–	–	–	X	X	–	–
C	–	X	X	–	–	–	–	X	X	–
D	–	X	X	–	–	–	–	X	X	–
E	–	–	X	X	–	–	–	–	X	X
F	–	–	X	X	–	–	–	–	X	X
G	–	–	–	X	X	–	–	–	–	X
H	–	–	–	X	X	–	–	–	–	X
I	–	–	–	–	X	X	–	–	–	–
J	–	–	–	–	X	X	–	–	–	–
K	–	–	–	–	–	X	X	–	–	–
L	–	–	–	–	–	X	X	–	–	–

6 Data Management, Analysis, and Reporting

Effective data management to ensure data quality, interpretability, security, longevity, and availability is critical to the success of the SCPN springs monitoring program (SOP #11). This long-term monitoring project will generate large quantities of data and numerous products. A well-organized digital file structure is essential to avoid confusion and potential data corruption. In this section we describe the procedures SCPN will follow to guarantee data quality and usability, and how these procedures will be merged with existing data strategies and databases for springs, which have been developed by NCPN (SOP #11).

6.1 Data Model

Springs monitoring data will be entered into a Microsoft Access database designed to accommodate all of the data on the various field forms. The database conforms to Natural Resource Database Template standards established by the national Natural Resource Stewardship and Science Inventory and Monitoring Program. The design includes standardized core tables for elements, such as Locations and Events, that are common to most monitoring datasets; as well as field data tables that can be customized to meet project data requirements. Field data tables are organized largely by SOP and are linked in time and space to enable integrated data analysis. Species, contacts, and attribute look-up tables provide standardized values for many data fields, and metadata tables track database revisions and data edits.

Hydrologic data are stored in an SCPN copy of the NCPN database and also exported to the NPStoret format so that they can be shared with the NPS Water Resources Division.

6.2 Data Entry

Data are acquired as specified in the protocol SOPs using two different methods for different data types: (1) digitally recorded by a GPS (spatial data) or portable data logger (water quality) and, (2) manually recorded

on paper datasheets (hydrology, vegetation and site characterization).

Digital data must be uploaded from the data recorder using specialized software and then converted into a format that is compatible with the NCPN database. Using digital data recording minimizes transcription errors and increases the efficiency of data collection. Data recorded on paper datasheets will be entered into the NCPN database as soon as possible after a field visit. Keeping current with data entry facilitates finding and correcting errors while information is still fresh in the minds of the field crew. Where appropriate, pick lists and domain limits will limit values entered into a field to ensure that only valid names or measures are entered. Field crew members should follow guidelines in the Springs Database User's Guide when entering data.

6.3 Data Verification, Validation, and Certification

Data verification occurs after data entry, when all records in the database are compared to the original paper datasheets and errors are corrected. Data validation is the process of reviewing data for range and logic errors. Although some validation features, such as range limits, are built into the database itself via data entry forms and queries, the project leader is also responsible for reviewing the data for content or context errors.

Data certification is the process of ensuring that the dataset (i.e., the working database) has been verified and validated for accuracy, is complete, and is fully documented. After the dataset is certified, it can be added to the master project database for archiving and storage and can be used for data analysis and reporting.

6.4 Metadata Procedures

All database objects (e.g., tables, fields) are defined and documented in a data dictionary and/or in Section 5 of a Federal Geographic

Data Committee (FGDC)-compliant metadata file. FGDC-compliant metadata are created for all spatial data. Information on data manipulations and the status of data verification and validation is recorded by users in a data management log.

6.5 Data Maintenance and Archiving

Digital data are archived in their native database format at the end of each field season, after all data have been entered, verified, and validated. A complete copy of the database in its native database format is also archived whenever the database version changes.

These version archives are supplemented by a platform-independent copy of the database tables in ASCII format, which is created using the Database Export utility developed and provided by NCPN (<https://irma.nps.gov/DataStore/Reference/Profile/2236823>). All archived files are designated as read-only. All files, both active and archival, are stored on a secure server with regular backup routines that include an off-site storage rotation.

Field forms and photographic prints or slides are irreplaceable resources that must be managed so that their quality and integrity are maintained long-term. Copies of these materials are used for project binders that are regularly used or referenced, while originals are accessioned into the SCPN archives for permanent storage and care.

6.6 Data Summary Reports and Briefs

SCPN staff will prepare Natural Resource Reports (NRR) (SOP # 12). These describe the field effort, data collected in a park, and highlight observed resources of management concern and general ecological observations of interest that were noted by the crew. In addition, data values, as compared to assessment points will be included in these reports. Assessment points are value levels assigned to resources that will elicit management concern. They provide a means of early detection of novel threats to a spring that may prompt immediate action or more intensive study. The NRR report will in-

clude recommended changes to protocol procedures and proposed future monitoring efforts. Information from NRR reports and other analyses is further condensed in 1–2 page briefs that provide resource managers with a concise summary of issues of concern.

6.7 Assessment Points

Assessment points for SCPN springs monitoring will be assigned for the following:

- Presence of target exotic plants or animals
- Novel disturbance (e.g., trespass cattle, increased social trailing)
- Shift in pH or conductivity, indicating possible aquifer contamination
- Repeated presence of *E. coli*, indicating possible fecal contamination

6.8 Data Analysis Reports

Once sufficient data are available, more comprehensive data analyses will be performed, with the overarching goal of describing the current condition (status) of springs vital signs and how spring condition is changing over time (trends) (SOP #12). Objectives of data analysis reports include:

1. Describe the current conditions (status) of a spring's vital signs using standard summary statistics and graphical techniques, and interpret these conditions in the context of management objectives.
2. Describe trends (if any) in springs vital signs using Seasonal Kendall tests for monotonic trends and Seasonal Rank Sum tests for step trends in water quantity and water quality and a mixed model for vegetation data.
3. Use modeling and other data exploration techniques to evaluate potential explanatory variables and covariates over broad thematic and spatial scales.
4. Evaluate the effectiveness of the sampling design using analyses of power to detect trends.

Status and trend reports will be generated every six sampling years for each park unit

conducting springs monitoring. Data will be analyzed for the period of record (long-term trends) and for any period where (1) a change is expected to have occurred due to a known impact at a site or (2) a change is apparent after a graphical inspection of the data record.

Because vital signs monitoring is designed to provide park managers with early warning of potential changes in park ecosystems,

we place greater than traditional emphasis on failing to detect a trend when a trend is present than on falsely detecting a trend that is not present. Data will be analyzed at $p \leq 0.1$ to provide more timely indications of trends to park managers (Field et al. 2004; Reynolds 2012). Once sufficient data have been collected to determine an empirical prior distribution, Bayesian modeling may improve trend detection (Efron 2013).

7 Budget

Estimated costs for conducting field-based springs monitoring in SCPN parks are shown in Table 5. Start-up field equipment costs are approximately \$14,000. After the first year, we anticipate that field equipment replacement and supplies will cost less.

Table 5. SCPN springs annual monitoring budget

Budget item	Annual cost (\$)
Water resources staff: Vegetation	17,500–19,300
Water resources staff: Hydrology	22,500–24,800
Equipment and supplies	2,000 – 3,000
Travel	400–600
Total	42,400–47,700

8 Safety

Crew safety requires that each crew 1) keep SCPN and park staff informed as to its activities, 2) evaluate risks and activities as they arise, and 3) be prepared to handle emergency situations.

The network has prepared a Field Safety Plan that specifically addresses conditions that may be encountered in the course of fieldwork conducted by its water resources, integrated upland, and bird monitoring crews (Southern Colorado Plateau Network 2013, revised 2018). All field crew members should thoroughly review the safety procedures in this plan at the beginning of every field season (SOP #1). In addition, the field crew should familiarize themselves with the backcountry guidelines, job hazard analyses, and emergency protocols for the parks in which they work, as applicable. It is the responsibility of network staff and cooperating employees to be aware of project-specific safety concerns and to take the necessary safety precautions.

At the beginning of the field season, each crew member should review the SCPN Field Safety Plan. Prior to each field hitch, crew members should meet together to discuss potential safety hazards and review documentation from previous seasons recorded in each site’s access information.

Monitoring crews spend considerable time in the backcountry under potentially hazardous conditions. The Field Safety Plan outlines the minimum procedures that the program must take to ensure crew safety. However, ultimately the responsibility lies with each crew member. Crew members must be prepared to ensure personal safety and survival for up to twenty-four hours in the backcountry. Crew members should use good judgment in the field to determine whether working conditions are acceptable. If a crew member feels that a situation is unsafe, s/he should take action to remove herself or himself from the situation. Safety should always be the first priority of every

SCPN crew member.

8.1 Risks Inherent in Springs Monitoring

Risks inherent in springs monitoring in general, and specifically to the sites selected in SCPN parks, include the following:

- Working alone. Field staff often will work alone when traveling to and from remote sites and when making measurements and collecting samples in the field. As a result, particular attention must be given to safety and safety check-ins.
- Long road trips. Travel between parks will require long road trips at all times of the year and under varied weather and road conditions.
- Backcountry travel. Accessing spring sample sites requires travel on secondary roads that are gravel or dirt; and some sites require hikes of up to three hours each way. The unsurfaced roads can become impassible during wet weather, and may remain muddy for several days after snowmelt. Hiking may be on or off trail through steep, rocky, sandy or muddy conditions. Hiking often occurs in washes that have flash flood potential. Accessing sample sites may require scrambling on sloping bedrock.
- Varied weather conditions. The Colorado Plateau region is characterized by weather conditions that vary considerably through the seasons, day-to-day, and hour-by-hour. Snow, wind, and temperatures below 0°F occur in the winter, and summer temperatures are often well above 100°F. Lightning is common during the summer monsoon storms. Hypothermia and heat-related injury are possible, and occasional discomfort is certain. Successful field work requires preparation for this wide range of conditions.
- Use of hazardous materials. Some of the water quality solutions and reagents used are hazardous and require proper storage, handling, and personal protection, including eye and skin protection.

9 Standard Operating Procedures

Table 5 lists the standard operating procedures (SOPs) that will guide SCPN springs monitoring. They are based on the SOPs in the NCPN Springs Monitoring Protocol

(Weissinger et al 2017), the NCPN Wadeable Streams Monitoring Protocol (Weissinger et al. 2018) and the NCPN Big Rivers Protocol (Perkins et al. 2018).

Table 5. Standard Operating Procedures (SOPs) required for the Southern Colorado Plateau Network Springs Monitoring Protocol Implementation Plan. SOPs are listed by task category and can found on the Integrated Resource Management Applications (IRMA) website under the project: Springs Monitoring Protocol Implementation Plan for Park Units in the Southern Colorado Plateau Network.

SOP Number and Title	Citation	Notes
1. Safety, Field Personnel, and Training	Weissinger et al. 2017. Standard Operating Procedure (SOP) # 1: Safety, Field Personnel, and Training	–
2. Sampling Overview and Equipment	Weissinger et al. 2017. Standard Operating Procedure (SOP) # 2: Sampling Overview and Equipment Needed	–
3. Site Establishment and Characterization	Weissinger et al. 2017. Standard Operating Procedure (SOP) #3: Site Establishment and Characterization	–
4. Site Map and Vegetation Characterization	Weissinger et al. 2017. Standard Operating Procedure (SOP) # 4: Site Map and Vegetation Characterization	–
5. Hydrologic Monitoring	Weissinger et al. 2017. Standard Operating Procedure (SOP) # 5: Hydrologic Monitoring	Used when groundwater is not being monitored.
6. Site Condition and Repeat Photopoints	Weissinger et al. 2017. Standard Operating Procedure (SOP) # 6: Site Condition and Repeat Photopoints	–
7. Hanging Gardens	Weissinger et al. 2017. Standard Operating Procedure (SOP) #7: Associated Measures at Hanging Gardens: Endemic Plant Census	–
8. Surveying	Weissinger et al. 2018. Standard Operating Procedure (SOP) #9: Stream Channel Surveying	NCPN Wadeable streams protocol will be used where groundwater monitoring is primary concern.
9. Groundwater Wells	Weissinger et al. 2018. Standard Operating Procedure (SOP) # 10: Well Installation and Hydrologic Monitoring	NCPN Wadeable streams protocol will be used where groundwater monitoring is primary concern.
10. Decontamination	Weissinger et al. 2017. Standard Operating Procedure (SOP) # 8: Decontamination Procedures	–
11. Data Management	Weissinger et al. 2017. Standard Operating Procedure (SOP) # 9: Data Management	–
12. Data summary, analysis and reporting	Weissinger et al. 2017. Standard Operating Procedure (SOP) # 10: Data summary, analysis and reporting	–
13. Revising the Protocol	Weissinger et al. 2017. Standard Operating Procedure (SOP) # 11: Revising the Protocol Narrative and SOPs	–

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Appendix A:

Current and Proposed Long-Term Monitoring in Southern Colorado Network Parks

Below is a list of monitoring protocols implemented in SCPN parks (indicated with an “X”), and where riparian and springs will be implemented in 2019. Riparian and Springs monitoring in parks are rated as high priority (H), medium priority (M) and low priority (L). In selecting the parks where we will implement riparian and springs protocols, we considered where monitoring was already taking place. In parks where we are not currently monitoring, we will implement riparian and/or springs protocols where applicable. In parks where we are conducting multiple monitoring projects, monitoring riparian and springs ecosystems would be a lower priority. See Appendix B for park acronym definitions.

Monitoring Protocol	Parks																	
	AZRU	BAND	CACH	CHCU	ELMA	ELMO	GLCA	GRCA	HUTR	MEVE	NAVA	PEFO	PETR	SAPU	WACA	WUPA	YUHO	# of Parks
Aquatic Macroinvertebrates	–	X	X	–	–	–	–	X	–	X	–	–	–	–	–	–	–	4
Habitat-based Bird Communities	–	X	X	–	–	–	–	X	–	X	–	X	–	–	–	X	–	6
Integrated Upland Vegetation and Soils	X	X		X	X	–	X	X	–	X	–	X	X	–	X	X	–	11
Water Quality	–	X	X	–	–	–	X	X	–	X	–	–	–	–	–	–	–	5
Vegetation Condition and Phenology, and Snow Cover Extent	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	19 ¹
# of protocols implemented (not including Riparian and Springs)	2	5	4	2	2	1	3	5	1	5	1	3	2	1	2	3	2	44
Riparian	H ²	L	1 of 2 ML ³	H	–	H	M	L	H	H/L ⁴	H ⁵	M	H	H	H	–	–	14
Springs	–	–	1 of 2 ML ³	M	–	–	H	L	–	L	–	L	–	–	–	H ⁶	H	8
# of Protocols proposed to be implemented with Riparian and Springs Included	3	6	6	4	2	2	5	7	2	7	2	5	2	2	3	4	2	64
# of Protocols to be implemented in 2019- with only high priority riparian and springs included.	3	5	4	3	1	2	4	5	2	6	1	3	2	1	3	4	2	51
1 This total includes Rainbow Bridge National Monument and Sunset Crater National Monument, which are not included in this table. This is the only monitoring to be conducted for these parks. 2 AZRU riparian will be groundwater wells only for high priority in 2019, other components will be low priority. 3 CACH will choose riparian or springs as medium priority and the other one will be low priority. Choice to be made in October 2019. 4 MEVE will be surface water only for high priority in 2019, the other components will be low priority. 5 NAVA will choose riparian or springs for monitoring in October 2019. 6 WUPA groundwater wells will be maintained by the park, SCPN will do data management.																		

Appendix B

Park Acronyms

Park	Abbreviation
Aztec Ruins National Monument	AZRU
Bandelier National Monument	BAND
Canyon De Chelly National Monument	CACH
Chaco Culture National Historical Park	CHCU
El Malpais National Monument	ELMA
El Morro National Monument	ELMO
Glen Canyon National Recreation Area	GLCA
Grand Canyon National Park	GRCA
Hubbell Trading Post National Historic Site	HUTR
Mesa Verde National Park	MEVE
Navajo National Monument	NAVA
Petrified Forest National Park	PEFO
Petroglyph National Monument	PETR
Rainbow Bridge National Monument	RABR
Salinas Pueblo Missions National Monument	SAPU
Sunset Crater Volcano National Monument	SUCR
Walnut Canyon National Monument	WACA
Wupatki National Monument	WUPA
Yucca House National Monument	YUHO

Appendix C

508 Accessible Table 2

Table 2. Springs selected for monitoring in SCPN parks, the spring category (sentinel site or random sample of hanging gardens), and spring type. High priority springs will be implemented first.

Category	Park	Spring	Spring Category	Spring Type	Comment
High Priority Springs	CACH	Wild Cherry Cattail	Sentinel	Rheocrene	Final selection will be made in October 2018.
High Priority Springs	CACH	Tsaile	Sentinel	Rheocrene	Final selection will be made in October 2018.
High Priority Springs	CACH	Many Cherry	Random sample	Hanging Garden	Final selection will be made in October 2018.
High Priority Springs	CACH	Twin Trail Canyon	Sentinel	Rheocrene	Final selection will be made in October 2018.
High Priority Springs	CACH	Bare Rock	Random sample	Hanging Garden	Final selection will be made in October 2018.
High Priority Springs	GLCA	Waterpocket Fold	Random sample	Hanging Gardens	Waterpocket Fold Navajo Sandstone Aquifer (higher priority) or the Wilson Mesa/Gray Mesa Aquifer (lower priority) as random sample of hanging gardens.
High Priority Springs	GLCA	Horseshoe Canyon	Sentinel	Hillslope	Horseshoe Canyon/East End/French Springs as sentinel springs.
High Priority Springs	GLCA	East End	Sentinel	Helocrene	Horseshoe Canyon/East End/French Springs as sentinel springs.
High Priority Springs	NAVA	Betatakin	TBD	Helocrene/Hanging Garden	Final selection will be made in October 2018.
High Priority Springs	WUPA	Heiser	Sentinel	Hillslope	Groundwater data collection by park, SCPN covers data management only.
High Priority Springs	YUHO	Aztec	Sentinel	Helocrene	—
Medium Priority Springs ¹	CHCU	Wijijii	Sentinel	Hanging Garden/Helocrene	Interested in veg and water quality.
Low Priority Springs ²	BAND	Frijoles	Sentinel	Rheocrene	Springs are lower than riparian.
Low Priority Springs ²	BAND	Apache	Sentinel	Rheocrene	Springs are lower than riparian.
Low Priority Springs ²	GRCA	TBD	TBD	—	—

1 To be implemented after High Priority Springs

2 To be Implemented after High and Medium Priority Springs

Table 2 (*continued*). Springs selected for monitoring in SCPN parks, the spring category (sentinel site or random sample of hanging gardens), and spring type. High priority springs will be implemented first.

Category	Park	Spring	Spring Category	Spring Type	Comment
Low Priority Springs ²	MEVE	Fewkes Canyon #4	Sentinel	Hanging Garden	—
Low Priority Springs ²	MEVE	Highway 160	Sentinel	Helocrene	—
Low Priority Springs ²	MEVE	Spruce Tree House	Sentinel	Hanging Garden	—
Low Priority Springs ²	MEVE	Morefield	Sentinel	Hillslope	—
Low Priority Springs ²	MEVE	Rock Canyon #2	Sentinel	Hanging Garden/Limnocrene	—
Low Priority Springs ²	PEFO	Kokopelli	Sentinel	Tinaja/Pool	Bedrock pool subject to scour events. Park is interested in water quality. Fairly stable for water quantity. Agate Bridge, Bear, and Painted Bridge are other springs.

1 To be implemented after High Priority Springs

2 To be Implemented after High and Medium Priority Springs

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

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National Park Service
U.S. Department of the Interior



Natural Resource Stewardship and Science

1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525

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