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Natural Resource Stewardship and Science

Springs and Seeps Monitoring Protocol for Park Units in the Northern Colorado Plateau Network

Version 1.1

Natural Resource Report NPS/NCPN/NRR—2023/2529









ON THE COVER

Clockwise from top left: alcove columbine, Freshwater Canyon, hanging garden (Arches National Park); Kirk's Spring (Canyonlands National Park). NPS/R. Weissinger.

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Natural Resource Report NPS/NCPN/NRR—2023/2529

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Executive Summary

Because of the scarcity of water on the Colorado Plateau and the disproportionately high use by flora and fauna, springs and seeps were quickly identified as an ecosystem of concern for the NCPN. Following the determination of network-wide vital signs, parks were asked to select their top priorities for monitoring. Four parks have implemented springs and seeps monitoring: Arches and Canyonlands national parks, and Hovenweep and Natural Bridges national monuments.

This monitoring protocol consists of a protocol narrative and 11 standard operating procedures (SOPs) for monitoring springs, seeps, and hanging gardens (aka "springs") in NCPN parks. The overall goal of the NCPN springs monitoring program is to determine long-term trends in hydrologic and vegetation properties in the context of changes in other ecological drivers, stressors, and processes. Specific objectives include describing the status and trends of water quantity (flow or stage as applicable), water quality (pH, specific conductance, temperature), and vegetation (endemic plant populations in hanging gardens, and vegetation species and cover).

This protocol narrative describes the justification, sampling design, and field methods for NCPN springs monitoring. Details may be found in the SOPs, which are listed in Chapter 1 and available at irma.nps.gov. Other aspects of the protocol summarized in the narrative include procedures for data management, analysis, and reporting; personnel and operating requirements; and instructions for how to revise the protocol.

Acknowledgements

Many people contributed to the development of this protocol. Abe Springer and Larry Stevens, of Northern Arizona University and the Museum of Northern Arizona, developed a conceptual model and inventory methods for springs on the Colorado Plateau as part of the scoping phase for long-term monitoring. John Spence, Glen Canyon National Recreation Area, is a regional expert on hanging gardens who developed much of the approach to describing vegetation at Colorado Plateau hanging gardens used here. Staff from the National Park Service Chihuahuan Desert, Mojave Desert, Sonoran Desert, and Southern Colorado Plateau networks and the U.S. Forest Service Groundwater Dependent Ecosystem Monitoring Development Team participated in a workshop to develop vital signs and indicators. The Northern Colorado Plateau Network monitoring effort builds on efforts initiated at the Southeast Utah Group of parks by former park ecologist Charlie Schelz. Tom Philippi (NPS Inventory & Monitoring Division), John Tipton (Colorado State University), and William Gould (New Mexico State University) provided statistical review at key points during protocol development. Evan Gwilliam (Sonoran Desert Network) and Joe Gurrieri (U.S. Forest Service) improved the protocol with their thoughtful reviews.

Revision History Log

Previous version #	Revision date	Author	Changes made	Reason for change	New version #
1.00	Dec 2022	R. Weissinger	Update hanging-garden methods and analysis	Changes to methods and analysis	1.1

1 Background

This monitoring protocol consists of this protocol narrative and the following standard operating procedures (SOPs), available at https://irma.nps.gov/DataStore/Reference/Profile/2240107:

- SOP 1 – Safety, Field Personnel, and Training
- SOP 2 – Sampling Overview and Equipment Needed
- SOP 3 – Site Establishment and Characterization
- SOP 4 – Site Map and Vegetation Characterization
- SOP 5 – Hydrologic Monitoring
- SOP 6 – Site Condition and Repeat Photopoints
- SOP 7 – Associated Measures at Hanging Gardens: Endemic Plant Census
- SOP 8 – Decontamination Procedures
- SOP 9 – Data Management
- SOP 10 – Data Summary, Analysis, and Reporting
- SOP 11 – Revising the Protocol Narrative and SOPs

1.1 Program overview

The core mission of the National Park Service (NPS) is to preserve and protect natural and cultural resources for the enjoyment of future generations. The NPS Inventory and Monitoring (I&M) Division was created to provide managers with credible scientific information about park natural resources to inform management decisions. The Northern Colorado Plateau Network (NCPN) serves 16 national park units throughout Utah, western Colorado, southern Wyoming, and northern Arizona.

In 2003, NCPN staff solicited input on natural resources of concern and ecosystem indicators known as "vital signs" from several hundred NPS staff and regional and national experts (O'Dell et al. 2005). Because of the scarcity of water on the Colorado Plateau and the disproportionately high use by flora and fauna, springs and seeps were quickly identified as an ecosystem of concern for the NCPN. Four parks have implemented springs and seeps monitoring: Arches National Park (NP), Canyonlands National Park (NP), Hovenweep National Monument (NM), and Natural Bridges National Monument (NM) (Figure 1-1). These four parks are managed jointly as the Southeast Utah Group (SEUG).

Potential vital signs were evaluated for management significance and utility, ecological significance, scientific validity, feasibility and cost of implementation, and signal-to-noise ratio.

Three vital signs are targeted for springs and seeps monitoring: (1) water quantity, (2) water quality, and (3) vegetation species composition, 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 Arches, Canyonlands, and Hovenweep. Vegetation species cover and endemic-plant counts are sampled at a random selection of hanging gardens at Arches and Natural Bridges. For all indicators, some sites are sampled annually, while others are sampled on a rotating basis.

Related NCPN monitoring efforts, such as water quality (Thoma et al. 2009) and wadeable streams monitoring (Weissinger et al. 2016), are conducted at additional sites and parks.

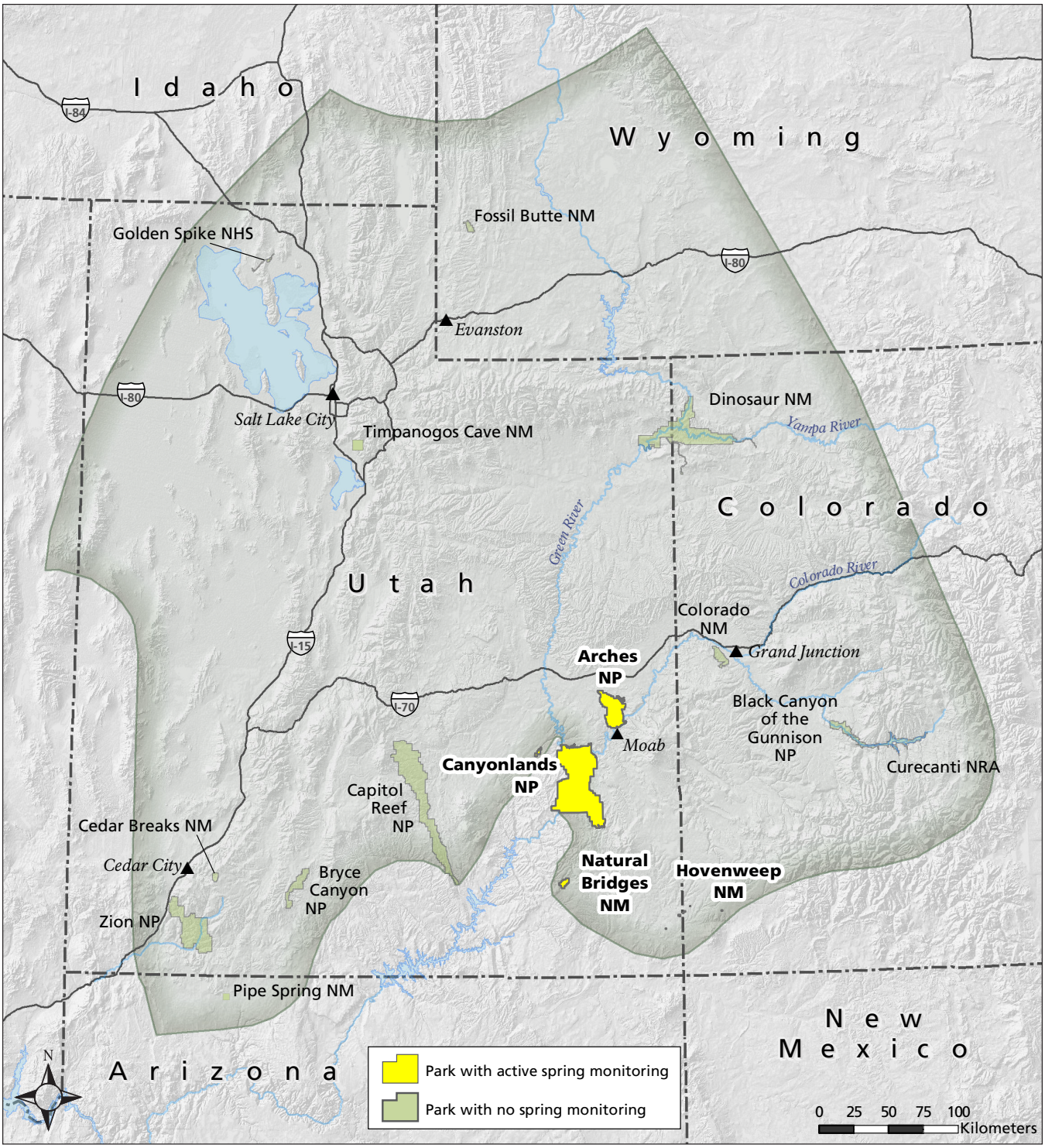


Figure 1-1. Overview of Northern Colorado Plateau Network parks. Parks participating in springs and seeps monitoring are shown in yellow and bolded.

1.2 Development of the monitoring program

The primary purpose of vital signs monitoring is to provide park managers with scientifically credible, relevant data on the status and trends of selected park resources as a basis for making decisions, working with other agencies, and communicating with the public to protect park natural systems and native species. Vital signs are defined as physical, chemical, and biological elements and processes of park ecosystems that represent the overall health or condition of the park, known or hypothesized effects of stressors, or elements that have important human values. The goals of vital signs monitoring include:

1. Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
2. Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
3. Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other altered environments.
4. Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment.

The approach taken by NCPN in selecting vital signs involved three stages:

1. Identify key resources and stressors.
2. Determine measurable ecosystem attributes associated with resources and stressors.
3. Review and prioritize list of candidate vital signs.

NPS vital signs and indicators must meet the following criteria:

1. **Management Significance and Utility.** Vital signs must provide information that is meaningful and useful to park managers.
2. **Ecological Significance and Scientific Validity.** Vital signs must be ecologically significant and clearly justified on the basis of peer-reviewed literature and a scientifically sound conceptual framework.
3. **Feasibility and Cost of Implementation.** Sampling, analysis, and interpretation of vital signs must be technically feasible and cost-effective. For purposes of vital-sign evaluation, a cost-effective vital sign is defined as one with a high benefit:cost ratio, i.e., information benefits are high relative to total costs.
4. **Signal:Noise Ratio (Response Variability).** Vital signs must be characterized by patterns of variability that are well understood and possess a high signal:noise ratio. That is, variability attributable to anthropogenic stressors must be high relative to variability attributable to natural processes or measurement errors.

Following an initial round of workshops and discussions with park staff and scientific colleagues, the NCPN proposed monitoring selected springs, seeps, and hanging gardens for long-term trends in discharge, core and site-specific water chemistry parameters, habitat area, vegetation composition and structure, and diversity and abundance of aquatic and riparian invertebrates. NCPN parks expressing interest in springs monitoring included Arches NP, Black Canyon of the Gunnison National Park, Canyonlands NP, Capitol Reef National Park, Curecanti National Recreation Area, Dinosaur National Monument, Hovenweep NM, Natural Bridges NM, and Zion National Park (O'Dell et al. 2005).

Following a three-year programmatic review that included park and I&M staff, the scope of NCPN springs monitoring was reduced to the final four parks included in the current monitoring plan: Arches, Canyonlands, Hovenweep, and Natural Bridges (D. Perkins, pers. comm.). The reduction in effort was primarily spurred by a re-evaluation of the affordable effort. Parks selected their highest-priority monitoring protocols based

on management interest. Protocol development and pilot testing then began, using the parameters described below.

Discharge. Previous measurements at springs in SEUG were used to determine the power to detect trends using monthly flow and stage measurements (Weissinger and Moran 2013). Previously sampled springs with unstable flow monitoring locations (e.g., alluvial wash bottoms subject to geomorphic change from flooding) were highly variable and had limited potential for detecting trends. The scope of sampling was narrowed to springs with measurable flow/stage at a stable (generally bedrock) measurement location.

Water chemistry. Water chemistry at springs is primarily tied to the geologic path and travel time of the spring aquifer and surface water–groundwater interactions (Hem 1985). Nutrients were not found to be highly related to disturbance categories during pilot sampling of sandstone springs on the Colorado Plateau (Weissinger et al. 2012). Laboratory analyses of water chemistry samples are relatively costly. Specific conductance, pH, and water temperature are good general indicators of water quality and are relatively inexpensive to monitor with portable probes. Changes in these parameters can be used to signal a need for additional water chemistry sampling. The scope of monitoring was narrowed to core water quality parameters.

Habitat area. Attempts to develop a repeatable method for monitoring habitat area at SEUG springs have been unsuccessful. GPS mapping is not feasible due to the topographic setting of most springs in SEUG, particularly hanging gardens. A pilot project using repeat photography and photo modeling software (PhotoModeler Scanner™) could not successfully classify vegetation and vegetated area. This indicator is on hold until a suitable method can be developed. Repeat photographs provide a qualitative record of habitat area over time.

Vegetation composition and structure. Attempts to develop a repeatable method for monitoring vegetation composition and structure have been problematic. A systematic, quadrat-based method was attempted during pilot sampling but was discontinued due to safety and resource concerns, particularly in the steep bedrock and colluvial slope settings at hanging gardens. Geomorphic surface-based methods were developed for descriptive use by Spence (as described in Spence 2008) and used for spring inventories during protocol development at hanging gardens throughout the Colorado Plateau (Springer et al. 2006). While not ideal for monitoring, they are at present our best attempt to delineate repeatable areas for sampling. Vegetation species, cover, and endemic-plant count data are collected by geomorphic surface and for the total spring area. An analysis of endemic-plant count data suggested that monitoring prioritize detecting changes in small populations of five endemic plant species (Weissinger 2022).

Diversity and abundance of aquatic and riparian invertebrates. Pilot sampling of aquatic invertebrates at sandstone springs indicated high variability and relatively low sensitivity to disturbance (Weissinger et al. 2012). There is no existing model for which species or communities accurately reflect habitat quality for SEUG springs. Aquatic invertebrate sampling also requires a high level of technical expertise and cost per sample. While still of high ecological significance, we eliminated this vital sign from the NCPN springs monitoring protocol due to limited management utility, the cost of implementation, and a poor signal:noise ratio.

1.3 Springs and seeps as a focus for monitoring efforts

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 serving as the primary source of water for more extensive aquatic and ripar-

ian 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).

As one of the primary sources of water in arid and semi-arid regions, springs are often focal points of human activity and human impacts (Shepard 1993; Hubbs 1995). Specifically, 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).

For purposes of this protocol, *springs* are defined as groundwater-dependent ecosystems with measurable flow or stage, while *seeps* are groundwater dependent ecosystems without measurable flow or stage. Springs and seeps vary tremendously in their surface expression. The essential driver of springs ecosystems is the source of the water and the geologic structure that brings it to the surface (Bryan 1919). The topographic setting of the spring emergence further diversifies available habitat and environmental conditions, resulting in a rich array of possible spring types. Figure 1-2 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 1-1). Most springs in the Southeast Utah Group of national parks emerge

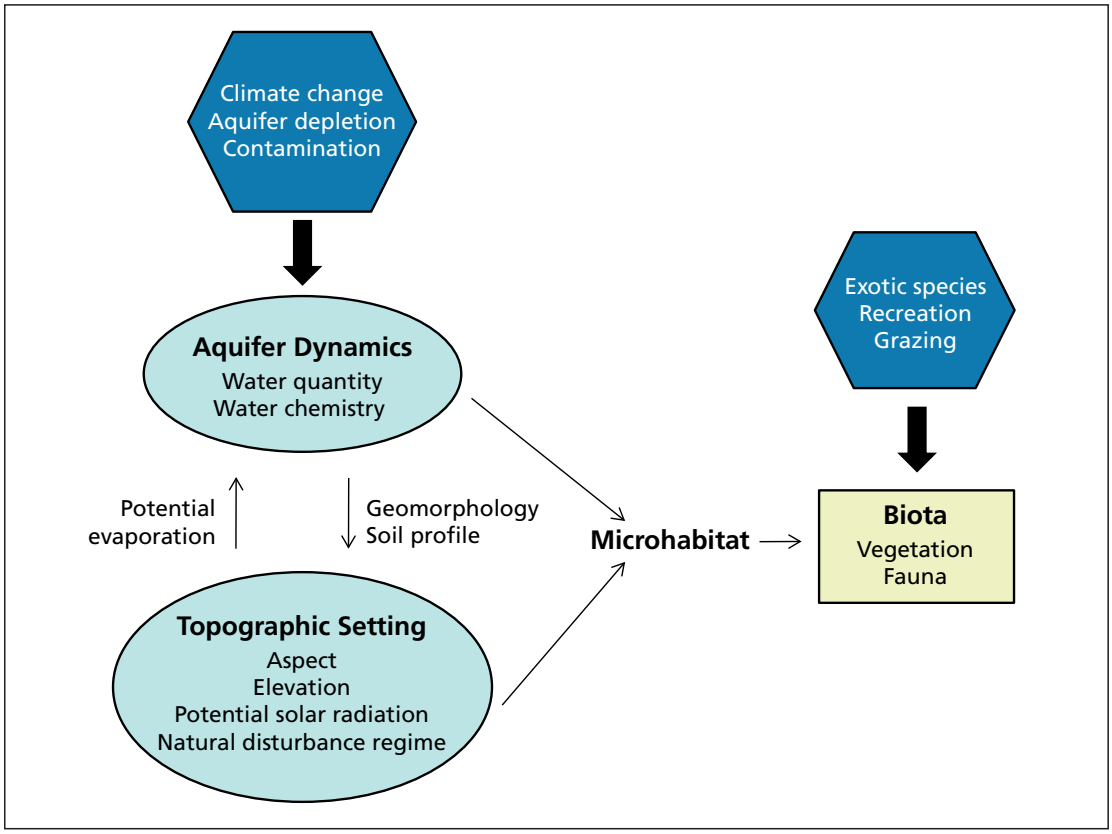


Figure 1-2. A general conceptual model of spring ecosystems of the Colorado Plateau. Hexagons represent significant potential stressors in NCPN park units. Ovals represent major drivers of ecosystem change and variability. The rectangle represents important structural components. Arrows describe functional relationships among system components. The model is constrained by state factors, including global climate, geology, time, and potential biota. Modified from Stevens and Springer (2004).

Table 1-1. Definitions of spring types (from Springer and Stevens 2009).

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

as pools (limnocrene), channelized flow (rheocrene), or seeplines along contact and bedding planes in sandstone (hanging gardens). In addition to these spring types, both low-gradient (helocrene) and high-gradient (hillslope) springs with diffuse, unfocused flow occur at NCPN parks.

Hanging gardens are a common spring type on the Colorado Plateau but are rare elsewhere. They develop in highly permeable sandstones along bedding planes or at the contact with a less permeable layer (Figure 1-3). The presence of perennial, low-flow seeps and the absence of flooding creates a stable, mesic environment. In eolian 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 and have become focal points for vascular plant endemism on the Colorado Plateau (Fowler 1995; Spence 2008) and are of special interest to the NCPN.

1.3.1 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 (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.

1.3.2 Water chemistry

The initial chemistry of spring water is determined by the geology and length of its groundwater path (Hem 1985). Short



Figure 1-3. Example of a hanging garden backwall and colluvial slope at Arches National Park.

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. SEUG springs are predominately from sandstone aquifers (Cudlip et al. 1999), and springs in the NCPN tend to have low dissolved solids (Springer et al. 2006).

1.3.3 Vegetation species composition

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 and others (2004) present 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 water 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.

1.4 Stressors of concern

Springs are often described as highly stable environments with relatively constant flow and water quality, yet disturbance is a natural component of spring ecosystems, and disruption of natural disturbance regimes can alter ecosystem structure and function (Kodric-Brown and Brown 2007). Moderate levels of disturbance have been associated with peaks in species richness in arid-land springs in the United States (Fleischman et al. 2006; Sada et al. 2005; Weissinger et al. 2012). The natural stability of springs in the NCPN is strongly affected by their geomorphic setting and the extent of their aquifer. Many springs are located in the alluvium of wash bottoms and are subject to intense flooding and solar radiation that result in removal of organisms and substrate

and fluctuations in water availability, solute concentrations, and temperature.

Novel and extreme disturbance can severely alter spring ecosystems and endanger the species that rely upon them (Sada and Vinyard 2002). Disturbances of concern in the NCPN include climate change, aquifer depletion, aquifer contamination, exotic species, fire, recreation, and livestock grazing. Additional regional stressors include flow alteration, development of the spring area, and surface water pollution (Stevens and Springer 2004).

1.4.1 Climate change

Current climate change models indicate that the U.S. Southwest faces an imminent increase in aridity due to decreased snowpack, increased temperatures, and increased drought frequency (Seager et al. 2007; Seager et al. 2013). Much uncertainty currently exists in how climate change will affect the amount, timing, and frequency of precipitation and, thus, groundwater recharge (Crosbie et al. 2012; McCallum et al. 2010; Ng et al. 2010). Aquifers underlying vegetated drylands receive little to no recharge (Scanlon et al. 2005), and many dryland springs in basin settings rely on aquifers decoupled from recent changes in climate. In contrast, localized springs with shallow aquifers, such as those found in jointed bedrock systems, allow for modern recharge and may be sensitive to modern changes in climate (Green et al. 2011).

While the residence time of most spring water in the region is unknown, groundwater dating at three hanging gardens in the Seven Mile and upper Courthouse Wash drainages of Arches National Park estimated that recharge consisted of precipitation dating from 1950 at the earliest (Kirby 2007), with a more refined estimate of 0–30 years before present (Masbruch et al. 2010). Due to the relatively rapid cycling of precipitation in these systems, hanging gardens at Arches NP and Natural Bridges NM are likely to be sensitive to climate change.

1.4.2 Aquifer depletion

Groundwater extraction is a common, immediate threat to many arid-land springs, and there are many examples of springs that have been depleted to the point of extinction (Ponder 2004; Unmack and Minckley 2008). Increasing aridity due to climate change will likely increase demand for groundwater, imperiling the extent of groundwater-dependent ecosystems, such as springs and seeps (Green et al. 2011; Klove et al. 2014). Agriculture, urban development, and oil and gas development can all have direct impacts on aquifer levels, while practices such as overharvesting of timber and livestock grazing may reduce the infiltration capacity of the landscape and negatively affect aquifer recharge rates (Pringle 2000). In addition to an immediate loss of available habitat, declines in the water table could also have indirect impacts, such as an increase in soil salinity (Patten et al. 2008). Because aquifer recharge areas, rates, and flow patterns are often poorly known, it can be difficult to predict the effects of novel development or land-use practices on specific springs.

1.4.3 Aquifer contamination

Aquifer contamination can change the water quality and water chemistry of spring water. Contamination can come from urban runoff, infiltration of pollutants from agricultural lands, wastewater treatment systems, and leaky well casings at oil and gas developments (Pringle 2000). Wastewater indicators and pesticides have been found in NCPN springs (Weissinger et al. 2013), indicating some level of movement from the surface to groundwater or direct contamination at the spring site from recreation or atmospheric deposition.

1.4.4 Exotic species

Non-native species introductions can have significant impacts on spring ecosystem species assemblages, food webs, and geomorphology (Dinger et al. 2005; Hendrickson et al. 2008). Introduced crayfish (Stumpf 2007) and bullfrogs are novel predators that affect NCPN spring invertebrate and amphibian communities. In semi-arid systems, mesic ecosystems, such as springs, also tend to be highly prone to colonization by non-native plants (Stohlgren et al. 1999). Additional

disturbances may make a spring more prone to invasions. Exotic vascular plant richness peaked at intermediate disturbance levels in Great Basin springs, while native vascular plant richness and cover decreased with increasing disturbance (Fleishman et al. 2006).

1.4.5 Recreational use

Recreational use by park visitors is the most common on-site disturbance at SEUG springs (Weissinger et al. 2012). Visitors may trample vegetation, destabilize soils, increase water turbidity, and introduce exotic organisms. Collectors and researchers may selectively impact certain park biota. Hanging gardens in particular are highly susceptible to erosive disturbances because their colluvial slopes are saturated with water and often have slopes of 65 degrees or greater (May et al. 1995).

1.4.6 Livestock grazing

Livestock grazing has shown inconsistent effects at arid-land springs. The removal of livestock from arid springs that evolved with native grazing pressure can result in a rapid increase in vegetation cover and transpiration that may dry the spring entirely (Kodric-Brown and Brown 2007), but Meretsky (2008) documented that native herbivory at springs at Grand Canyon and Zion national parks was low. NCPN research indicates that livestock grazing is correlated with reduced plant cover, changes in aquatic macroinvertebrate communities, and increases in turbidity and fecal indicator bacteria at sandstone springs on the Colorado Plateau (Weissinger et al. 2012). Similarly, grazing at arid springs in Australia was correlated to increased bare ground, water turbidity, and a lack of tall herbaceous vegetation (Ens et al. 2010). Diversions of spring water for livestock use is also a common stressor associated with grazing in the region (Grand Canyon Wildlands Council 2002). SEUG springs are rarely affected by trespass livestock grazing at time of writing, but livestock grazing occurred into the 1980s at some sites, and livestock and native ungulate grazing is an important land use at other NCPN springs.

1.5 History of springs research in NCPN park units

NCPN springs have interested managers and researchers for many years. Much early inventory work was spurred by the search for culinary water supplies (e.g., Huntoon 1978; Marine 1958; Sumsion 1967). Several parks conducted further inventories to expand their baseline knowledge of spring locations (e.g., Foster et al. 2000; Kehrer 1985). Springs have often been included in studies incorporating water quality measures, and a summary of visits and results is available in a series of NPS reports (e.g., NPS-WRD 2003). Most studies of springs-related vegetation in NCPN parks have focused on hanging gardens. This literature is summarized in Weissinger and others (2011). An overview of literature pertaining to each park's water resources, including springs, can be found in Evenden and others (2002).

Previous monitoring at NCPN springs has been limited to the Southeast Utah Group of parks. The Southeast Utah Group has conducted water quality monitoring at selected spring sites since the early 1980s and added monthly measurements, including flow, in the early 2000s (Schelz and Moran 2004, 2005a, 2005b; Van Grinsven et al. 2010; Hackbarth and Weissinger 2013). In a separate study, monthly spring flow monitoring began at four sites in Arches National Park in 2001 (Moran 2011), and a short-term spring flow and pool monitoring program was implemented at several springs in Hovenweep National Monument in 2004. Field-level counts of aquatic macroinvertebrates were included in SEUG's water quality monitoring from 1997 through 2010.

NCPN determined that key information was missing from this data record and funded an inventory of selected springs that included water quantity, water quality, vegetation, and macroinvertebrate sampling (Springer et al. 2006). Additional work on rare plants occurred at hanging gardens in Arches NP and Natural Bridges NM (Weissinger et al. 2011) and on aquatic macroinvertebrates at six parks (Weissinger et al. 2012).

2 Program Goals and Measurable Objectives

The overall goal of the NCPN springs monitoring program is to determine long-term trends in hydrologic and vegetation properties 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 include describing the status and trends of:

- Water quantity
  - Flow or stage as applicable
- Water quality
  - pH
  - Specific conductance
  - Temperature
- Vegetation
  - Endemic plant populations (hanging gardens only)
  - Vegetation species and cover

In addition, springs monitoring includes reporting the status of specific indicators of 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)

The expected relationship between NCPN springs monitoring indicators and stressors is detailed in Table 2-1.

Local weather station data can be used to interpret responses. Remote sensing can be used to determine change in vegetation caused by land use or climate change at local and regional scales.

Table 2-1. Predicted responses of vital sign indicators to stressors in NCPN parks.

Vital sign	Indicator	Predicted stressor response
Water quantity	Flow or stage	Decrease due to aquifer depletion; unknown response to climate change
Water quality	pH	Sudden shift due to aquifer contamination; possible change due to change in spring flow
Water quality	Specific conductance	Sudden shift due to aquifer contamination; possible change due to change in spring flow
Water quality	Temperature	Increase due to climate change or grazing; possible change due to change in spring flow
Water quality	Fecal coliform concentration	Increase due to recreation or grazing
Vegetation	Endemic plant count	Decrease due to climate change or aquifer depletion; unknown response to recreation or grazing
Vegetation	Native richness and cover	Decrease due to exotic species, recreation, or grazing
Vegetation	Wetland richness and cover	Decrease due to climate change or aquifer depletion

3 Sampling Design

3.1 Design overview

NCPN has two approaches to springs monitoring: (1) sentinel sites at Arches NP, Canyonlands NP, and Hovenweep NM, and (2) randomly selected hanging gardens at Arches NP and Natural Bridges NM.

3.1.1 Sentinel sites

Sentinel sites are stand-alone monitoring locations that cannot be used to infer results to spring populations as a whole. They are visited monthly from March to November within a sample year and are revisited using a panel rotation of two years of sampling followed by two years of rest. A subset of sites is monitored yearly to track responses to unpredictable or cyclical climate events. Primary monitoring indicators at sentinel sites are water quantity and water quality. Hanging gardens at Canyonlands NP are also sampled as sentinel sites.

3.1.2 Hanging gardens

Randomly sampled hanging gardens are used to gain an understanding of the health of hanging garden populations. Hanging gardens are visited once during the growing season within a sample year, and revisited using a panel rotation of one year of sampling followed by two years of rest. A subset of sites is monitored yearly to track responses to unpredictable or cyclical climate events. The primary monitoring indicators at hanging gardens are endemic plant populations.

3.2 Spatial design description and rationale

Springs are highly complex ecosystems that naturally vary in water quantity, water quality, biological communities, topographic setting, and disturbance regimes. As such, 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 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

Table 3-1. High-priority monitoring sites selected by Southeast Utah Group staff.

Park	Site name	Spring type
Arches NP	Cordova Canyon South	Hanging garden with pool
	Poison Ivy Spring	Hanging garden with pool
	Sevenmile Boundary Spring*	Hanging garden with pool
	Sleepy Hollow Spring	Hanging garden with pool
	Courthouse Boundary Spring	Rheocrene in wash bottom
Canyonlands NP (Island in the Sky District)	Alcove Spring	Hanging garden
	Cabin Spring	Rheocrene
	Holeman Spring	Hanging garden with outflow
	Neck Spring	Hanging garden
	Syncline Loop	Hanging garden with outflow
Canyonlands NP (Needles District)	Big Spring	Hanging garden with pool
	Kirk's Cabin Spring	Rheocrene in wash bottom
	Little Spring	Rheocrene in wash bottom
Hovenweep NM	Goodman Point	Rheocrene
	Hackberry Spring	Limnocrene in alcove
	Square Tower Spring	Limnocrene in alcove
Natural Bridges NM	Upper Armstrong	Hanging garden with outflow

*Site is outside NPS boundaries.

a random sample of sites, and the bulk of NCPN's springs monitoring effort focuses on sentinel sites.

3.2.1 Sentinel sites

The Southeast Utah Group selected sentinel monitoring sites by management priority, the presence of historical data records, access, and a stable flow-sampling location (Table 3-1). Other criteria that were considered, but ultimately rejected, for site selection 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), and incorporating some type of spatial balance (remote and difficult access in much of Arches and Canyonlands NPs). Management concerns include recreational use, invasive plants, proposed developments outside park boundaries, and surrounding agricultural and extractive land uses.

In Arches National Park, proposed sampling sites are clustered in the northern sections of Courthouse Wash and Salt Wash within park boundaries (Figure 3-1). These areas are fairly remote, but most sites receive limited hiking use. Courthouse Boundary Spring, while within the park, is located outside of park fencing and receives impacts from trespass livestock and off-road vehicle use. Proposed gas, oil, and potash mining leases could affect upgradient aquifers at all of these sites. Poison Ivy, Sevenmile Boundary, Sleepy Hollow, and Courthouse Boundary springs have a 10-year flow data record from SEUG sampling, and SEUG plans to continue monitoring flow on a monthly basis for at least three of these sites. NCPN will augment this sampling by adding site characterization, water quality, and vegetation measures at these sites. After evaluation of the pilot data, it was determined that Courthouse Boundary Spring cannot be sampled accurately with its current geomorphology. SEUG will reinstate flow monitoring if a stable monitoring location re-emerges (e.g., a bedrock outcrop currently buried under sediment). The remaining site is supported by NCPN.

Canyonlands National Park (Figure 3-2) has fewer known direct threats to proposed monitoring sites. Many of the springs are located directly adjacent to maintained hiking trails, where visitor impacts are a concern. Alcove Spring and Neck Spring have exposed surface water but no stable flow monitoring location; these sites will be monitored for vegetation but not flow. The White Rim sandstone contains many small hanging gardens, but a reconnaissance of accessible areas determined none was suitable for monitoring, primarily due to access and a lack of a stable flow monitoring location. Holeman Spring, in the Island in the Sky district, was reconnaissanced in 2013, but the approach was deemed too difficult for monthly monitoring. Monitoring was initiated at Big Spring in the Needles district in 2014, but there was no stable flow monitoring location, and this site has been suspended.

Hovenweep National Monument consists of several small protected parcels embedded within a landscape of active agricultural and gas fields. The limited protected area may make these springs particularly vulnerable to off-site aquifer drawdown or contamination. As such, the primary known springs within the monument are all included for monitoring (Figure 3-3). SEUG will continue water quantity monitoring at Square Tower Spring, and NCPN will augment this site with vegetation and site characterization data.

There are few flowing springs at Natural Bridges National Monument, excepting groundwater intersections with the wash bottoms of White and Armstrong canyons. Many of the wash-bottom springs shift with the seasons and with flooding events and would be difficult to monitor accurately. The proposed monitoring site at Upper Armstrong Spring (Figure 3-4) had measurable flow during a single visit in September 2009, but follow-up monthly sampling in 2012 indicated that the site's flow is too diffuse to reliably measure. Like Upper Armstrong Spring, the majority of springs at Natural Bridges NM are hanging gardens without measurable flow. A strategy for monitoring these sites is detailed in the next section.

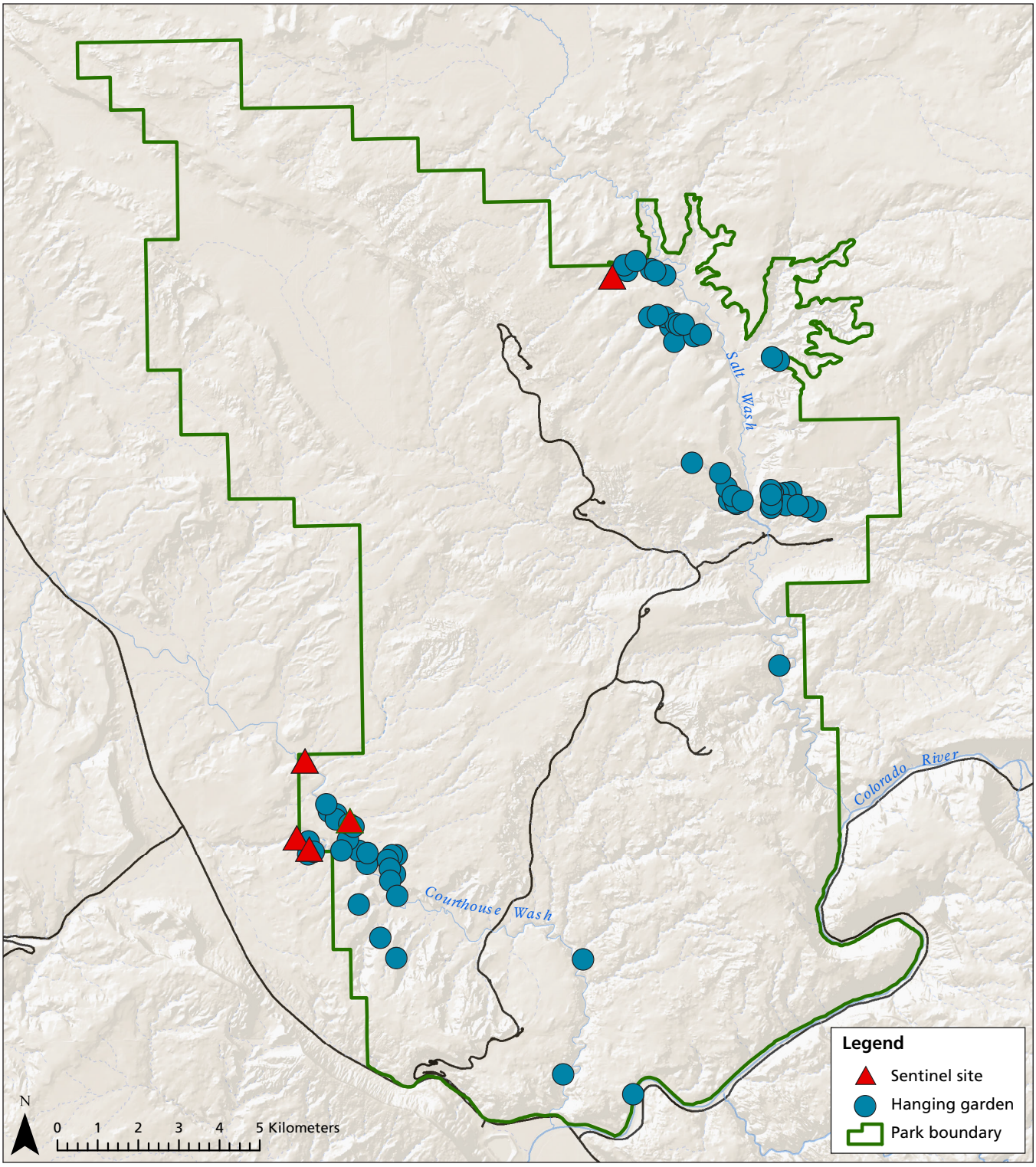


Figure 3-1. Locations of sentinel monitoring sites and hanging gardens for random sampling at Arches National Park.

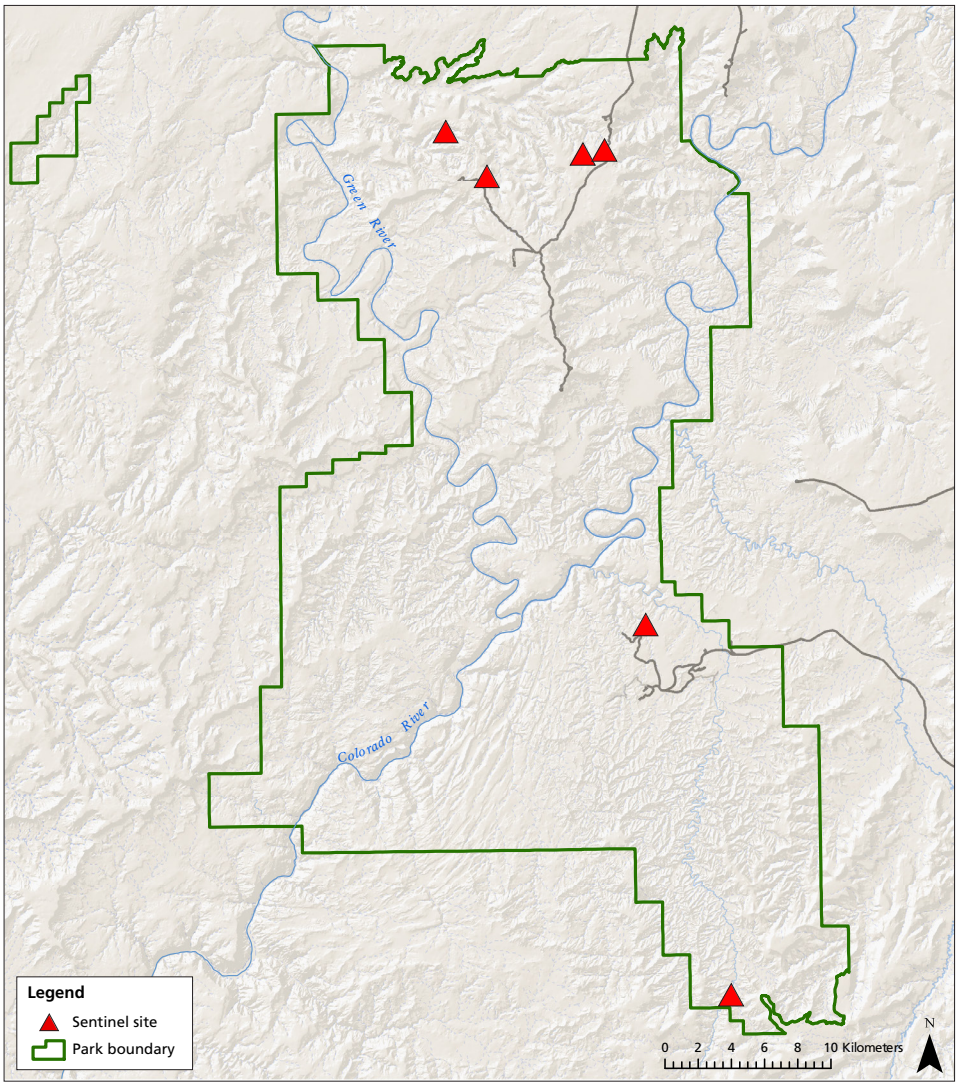


Figure 3-2. Locations of sentinel monitoring sites at Canyonlands National Park.

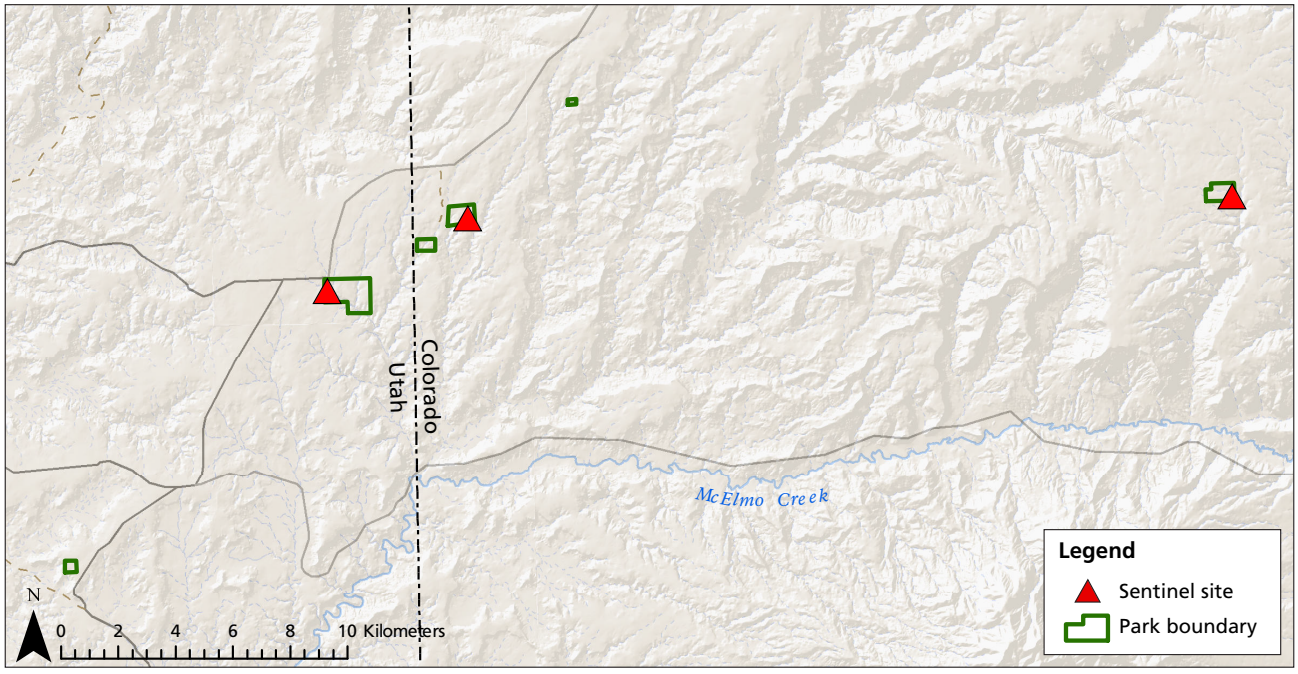


Figure 3-3. Locations of sentinel monitoring sites at Hovenweep National Monument.

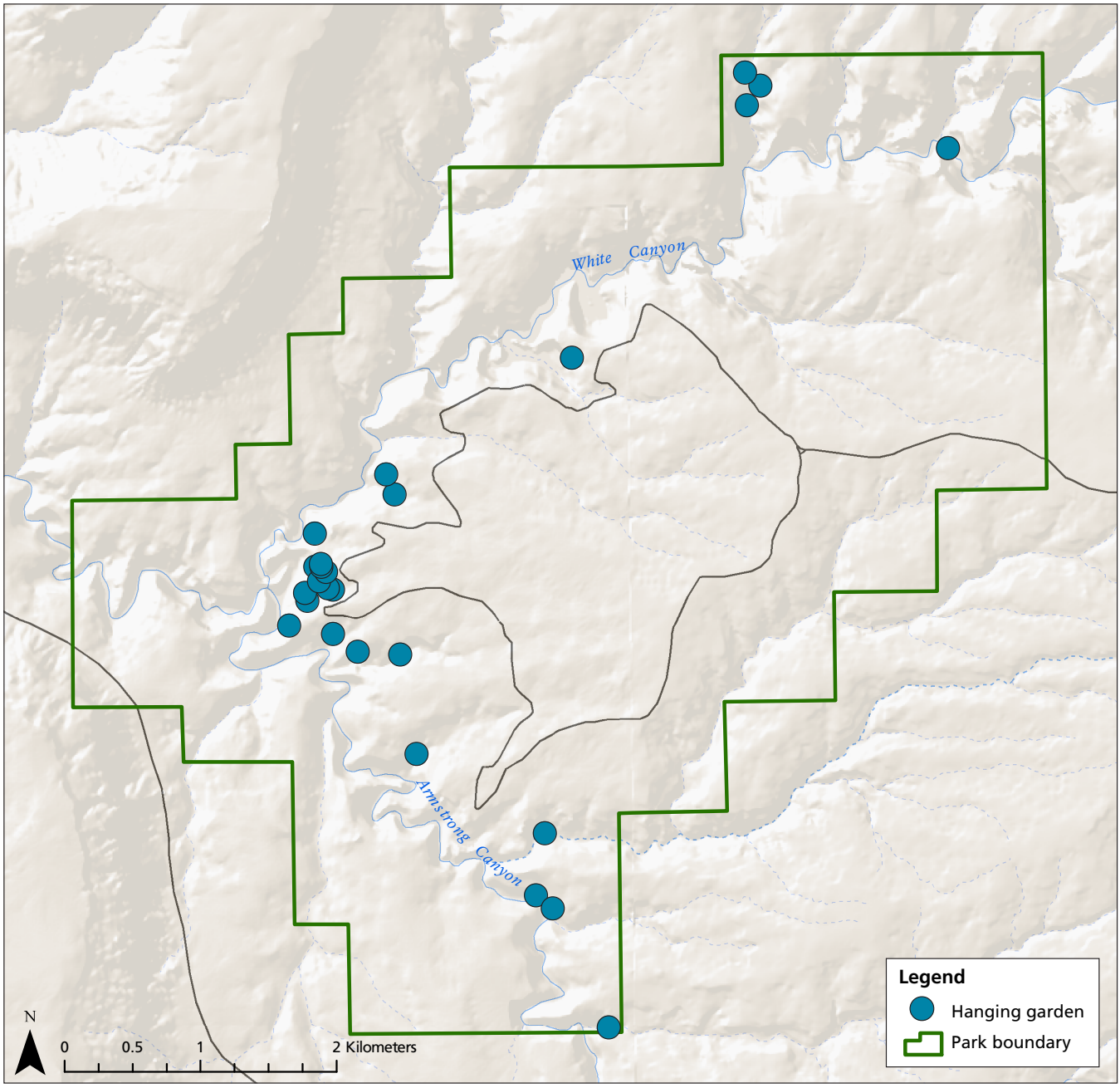


Figure 3-4. Locations of hanging gardens for random sampling at Natural Bridges National Monument.

3.2.2 Randomly sampled hanging gardens

The exceptions to the sentinel approach are hanging gardens at Arches National Park and Natural Bridges National Monument. Hydrogeologic studies suggest that hanging gardens in these parks have highly localized aquifers (May et al. 1995; Cudlip et al. 1999; Hurlow and Bishop 2003). 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.

Populations of hanging gardens at Arches NP and Natural Bridges NM were documented during a rare-plant inventory in 2009 and 2010 (Weissinger et al. 2011). An attempt to inventory hanging gardens at Island in the Sky in Canyonlands National Park determined that the accessible population was too small to support a random draw, so specific sites were selected to be monitored as sentinel sites (see Section 3.2.1). Hanging gardens at Arches NP were divided into three geographic populations: Courthouse Wash, Upper Salt Wash, and Freshwater Canyon/Delicate Arch (see Figure 3-1). Hanging gardens at Natural Bridges NM are considered one population (see Figure 3-4). Upper Armstrong Spring, discussed above, is part of the random draw after being removed as a sentinel monitoring location.

Within each population, individual hanging gardens 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 is sampled in the randomly generated order until the affordable sampling effort is reached.

3.3 Revisit design description and rationale

3.3.1 Sentinel sites

Sentinel sites are visited monthly from March to November within a sample year and are revisited using a panel rotation of two years of sampling followed by two years of rest (Table 3-2). A subset of sites is monitored yearly to track responses to unpredictable or cyclical climate events.

Up to 10 years of historic monthly data collected by SEUG 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.

3.3.2 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 and provide a better estimate of the status of the population. During the first full panel of sampling (2013–2022), sites were sampled for two years in a row, then rested for several years (Weissinger et al. 2017). After analyzing the data, we determined that annual variation could not be meaningfully incorporated into the statistical analysis (Weissinger 2022). The sampling design was updated so randomly sampled hanging gardens are sampled one year, then rested for two years (Table 3-3). A subset of sites, selected for their resistance to trampling, is monitored yearly to track responses to unpredictable or cyclical climate events.

Table 3-2. List of sentinel monitoring sites with sample years.

Park	Site name	Year				Monitoring[2]	
		1	2	3	4	Water	Veg
Arches NP	Cordova Canyon South	–	–	X	X	NCPN	NCPN
	Poison Ivy[1]	X	X	X	X	SEUG	NCPN
	Sevenmile Boundary[1]	X	X	X	X	SEUG	NCPN
	Sleepy Hollow[1]	X	X	X	X	SEUG	NCPN
	Courthouse Boundary Spring[3]	/	/	/	/	SEUG	NCPN
Canyonlands NP (Island in the Sky District)	Alcove Spring[4]	–	–	X	X	–	NCPN
	Cabin Spring[1]	X	X	X	X	NCPN	NCPN
	Neck Spring[4]	X	X	–	–	–	NCPN
	Syncline Loop	X	X	–	–	NCPN	NCPN
Canyonlands NP (Needles District)	Kirk's Cabin[1]	X	X	X	X	NCPN	NCPN
	Little Spring	–	–	X	X	NCPN	NCPN
Hovenweep NM	Goodman Point	X	X	–	–	NCPN	NCPN
	Hackberry House	X	X	–	–	NCPN	NCPN
	Square Tower	X	X	–	–	SEUG	NCPN

[1]Site sampled every year.
[2]"SEUG" indicates a measurement that is already a part of SEUG water quality or spring flow monitoring efforts. "NCPN" indicates a measurement that is being initiated by NCPN.
[3]Monitoring at Courthouse Boundary Spring is suspended until a stable monitoring location re-emerges.
[4]Sentinel hanging-garden location where water quantity and quality measurements are not possible. Hanging-garden methods will be used instead of sentinel methods at these sites, but there is no statistical inference to the hanging-garden population at Canyonlands NP.

Table 3-3. Proposed rotation of randomly sampled hanging gardens for each geographic population.

Site	Year*		
	1	2	3
A	X	X	X
B	X	–	–
C	X	–	–
D	X	–	–
E	X	–	–
F	–	X	–
G	–	X	–
H	–	X	–
I	–	X	–
J	–	X	–
K	–	–	X
L	–	–	X
M	–	–	X
N	–	–	X
O	–	–	X

*"X" = Sampled; "–" = not sampled.

Sites are added in random order. One site in each population that is easily sampled without excessive trampling impacts is visited each year. Fifteen hanging-garden locations total are sampled in each geographic population:

- Arches NP – Courthouse Wash (29 known accessible sites)
- Arches NP – Upper Salt Wash (20 known accessible sites)
- Arches NP – Freshwater/Delicate Arch (23 known accessible sites)
- Natural Bridges NM – (19 known accessible sites)

3.4 NCPN affordable effort

The NCPN currently conducts 11 different monitoring protocols, including seven that require intensive annual fieldwork. Because of budgetary and logistical constraints, the affordable field effort for springs and seeps monitoring was determined to be approximately 11 pay periods (PP) per year for a technician (GS-6/7 level employee). This affordable effort does not include additional time for data management, analysis, and reporting that is assumed to be a core part of year-round NCPN staff duties.

For sentinel sites with flow monitoring, NCPN will support an effort of 50 hours per month for a nine-month sampling season (March–November) for 1.5 technicians (a total of 450 hours for a GS-6/7 lead technician and 225 hours for a GS-4/5 subordinate technician; approximately 8 PP). SEUG will continue monthly flow monitoring at five sites using panels previously established for their springs and water quality monitoring program, for a total of approximately 480 hours (6 PP) of effort per year divided between two technicians. Vegetation composition data at sentinel sites is allotted approximately one PP per year.

The affordable effort for hanging-garden sites with no flow monitoring is approximately two PP per year for one technician. Allocations to various geographic areas are as follows:

- Arches NP – Courthouse Wash (29 known sites), 0.5 PP/yr
- Arches NP – Upper Salt Wash (20 known sites), 0.5 PP/yr
- Arches NP – Freshwater/Delicate Arch (23 known sites), 0.3 PP/yr
- Natural Bridges NM – (19 known sites), 0.7 PP/yr

3.5 Response design description and rationale

All methods are designed to minimize trampling and other research impacts at the site. Currently, no permanent infrastructure is proposed. A list of all monitoring metrics with more detailed descriptions is available in Appendix A.

3.5.1 Site characterization

Site characterization includes important information for interpreting responses at springs, including geology, aspect, potential solar radiation, elevation, spring type, and geomorphology. 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.

3.5.2 Vegetation species and cover

Vascular plant cover by species is listed for each geomorphic surface and for the total spring area, plus up to 50 meters of a spring-fed run-out channel. 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 in Welsh and others (2003), which is the authority for botanical nomenclature for SEUG.

3.5.3 Water quantity

Flow or stage is measured at a permanent location within the site. 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. Stage measurements are taken at pools with no outflow or in shallow groundwater piezometers.

3.5.4 Water quality

Water quality data are collected as near to the spring orifice as possible. When sufficient water is available, core parameters of pH, specific conductance, and water temperature are collected using a calibrated multiparameter probe. Fecal coliform sampling occurs at sites of management interest and consists of collecting a sample, immediately placing the sample on ice, and processing the sample within eight hours of collection using the IDEXX Colilert system.

3.5.5 Endemic-plant counts

Using a timed search based on site area, the number of endemic plant individuals by species is recorded for each hanging garden's backwall, alcove floor, and colluvial slope, and for the total spring area. Counts are recorded as numbers for 0–500 individuals, and then in classes of 501–1,000 and >1,000. Five perennial plant species had acceptable observer variability and have been selected for monitoring (Table 3-4; Weissinger 2022).

3.6 Rationale for selected methods

No standard methods for monitoring springs exist, although similar efforts were under development by the U.S. Forest Service (USDA-FS 2012) and other National Park Service I&M networks (e.g., Chihuahuan Desert Network, Mojave Desert Network) at time of writing. NCPN springs monitoring was developed in conversation with these efforts and has similarities in site characterization and selected monitoring indicators.

3.6.1 All sites

Site characterization, including vegetation composition, is based on inventory methods developed by Spence (as described in Spence 2008) and used in the 2005 NCPN spring inventory (Springer et al. 2006). Geology, elevation, aspect, slope, and potential solar radiation are important in determining microhabitat conditions at the many spring sites on the Colorado Plateau (Spence 2008). Spring size, complexity, and proximity to other springs also affect the diversity expected at a site. A site sketch map separates the spring into geomorphic surfaces that define the repeat monitoring areas for vegetation, water quantity, water quality, and repeat photographs.

3.6.2 Sentinel sites

Water quality and quantity methods are standard for the Northern Colorado Plateau Network and conform to National Park Service standards (Thoma et al. 2006; NPS-WRD 2002). Specific conductance is closely correlated to total dissolved solids and salinity. Water temperature and pH affect the dissolvability of materials in water, including gases such as oxygen. Abrupt changes in specific conductance and pH could indicate aquifer contamination and would signal a need for additional investigations.

3.6.3 Hanging gardens

At most hanging gardens in Arches NP and Natural Bridges NM, surface water is limited at best. Endemic plants are of inherent interest to park managers. As perennial, wetland species, the endemic plants targeted for monitoring may also be useful as a surrogate for water availability at hanging gardens where discharge cannot be measured.

Hanging gardens are particularly difficult to sample because of safety and resource impact concerns. Any type of systematic or random sampling would result in unacceptable risks to the field crew or impacts to the site. A double-observer pilot study of counts of endemic plants at hanging gardens was

conducted for two years at 24 hanging gardens in Arches, Canyonlands, and Natural Bridges. Because of low sample numbers, a simulated dataset based on the most common species, *Aquilegia micrantha*, was used to determine a preliminary power to detect trends (unpublished data, J. Tipton 8/22/13). The simulated ability to detect trend justified additional sampling. An analysis of the first full rotation of sampling indicated that the selected five of seven test species met observer-variability goals (Weissinger 2022). The initial panel also indicated that observers experienced with vegetation monitoring in hanging gardens had higher counts, while counts by less-experienced observers varied, sometimes widely. When there is observer turnover for endemic-plant counts, abrupt changes in the data record should be interpreted with caution.

Table 3-4. Endemic species and their presence in SEUG parks.

Family	Species	Counting unit	Note	Park*		
				ARCH	CANY	NABR
Asteraceae	*Cirsium rydbergii*	Rosette	–	P	P	P
Liliaceae	*Zigadenus vaginatus*	Individual	–	P	P	P
Orchidaceae	*Habenaria zothecina*	Individual	–	P	P	P
Primulaceae	*Primula specuicola*	Rosette	Rhizomatous	P	P	U
Ranunculaceae	*Aquilegia micrantha*	Individual	–	P	P	P

*P = Present in Park, U = Unconfirmed but suspected to occur in park.

4 Managing the Field Season

4.1 Field season preparations

Sampling dates should be scheduled and logistics organized prior to the start of the field season. This includes applying for and renewing research permits, hiring the field crew, arranging camping or park housing, and acquiring backcountry permits. All of the equipment and supplies should be organized, tested, and ordered to ensure availability by the beginning of the field season. Copies of the data sheets should be printed. Directions, revisit data sheets, and species lists should be generated for each spring.

Ample time should be allowed to process background checks and other paperwork for newly hired crew members. Before collecting data, field crew members must be trained in all monitoring procedures, such as multiparameter probe calibration and plant identification, and must review the entire protocol, especially the SOPs. The project manager must ensure that crew members understand all procedures and evaluate their understanding during training.

4.2 During the field season

During the field season, the field crew must ensure that park staff and safety contacts are notified of upcoming visits at least one week in advance. Test and calibrate all equipment prior to field visits. After returning from a field visit, enter and verify data as soon as possible. The project manager should review data promptly and go on periodic field audits to ensure all procedures are understood and followed by all data collectors.

4.3 End-of-season procedures

While all crew members are still available, the project manager should complete a protocol review, which entails asking crew members specific questions about the clarity and efficiency of all procedures and safety concerns, and acquiring general feedback.

The equipment list should be updated with the number of equipment items that are functional and available for the next field season. This updated list should be compared to perceived needs of the next season, and supplies should be replenished as necessary.

5 Data Management

Effective data management to ensure data quality, interpretability, security, longevity, and availability is critical to the success of the springs monitoring program. The NCPN has developed a data management plan (Beer et al. 2005) that describes these procedures in general terms. The following outlines the application of those procedures to springs monitoring. SOP #9 provides explicit instructions.

5.1 Data organization

This long-term monitoring project generates large quantities of data and numerous products, and a well-organized digital file structure is essential to avoid confusion and potential data corruption. Each NCPN project uses a similar folder structure replicated on both the active (X:\) and archive (R:\) network drives. Data for the current field season are stored on the X:\ drive. At the end of each field season, certified data, completed products, and other seasonal files are transferred to the permanent project folder on the R:\ drive, where they are stored in read-only format.

5.2 Data model

Springs monitoring data are entered into a Microsoft Access database designed to accommodate all data on the various field forms. The database conforms to Natural Resource Database Template standards established by the national 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 the NCPN database and also exported to the NPStoret format so that they can be shared with the NPS Water Resources Division.

5.3 Data entry

Data are acquired as specified in the protocol SOPs using two different methods: (1) digitally recorded by a GPS (spatial data) or portable datalogger (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 are 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 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.

5.4 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.

5.5 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.

5.6 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 NCPN archives for permanent storage and care.

The NCPN archives are located at the Western Archeological and Conservation Center (WACC) in Tucson, Arizona. All springs monitoring certified data and final data products, both digital and hard copy formats, are archived at WACC after each field season.

6 Reporting and Analysis

6.1 Data summary reports and briefs

Summary reports describe the field effort and briefly summarize data collected in a park. Summary reports also highlight observed resources of management concern and general ecological observations of interest that were noted by the crew (see below). These "assessment points" are designed to provide early detection of novel threats to a spring that may prompt immediate action or more intensive study:

- 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

The summary report includes an overview of any necessary changes to protocol procedures and proposed future monitoring efforts. Information from summary reports and other analyses is further condensed in 1–2 page briefs that provide resource managers with a concise summary of issues of concern.

6.2 Data analysis reports

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

1. Describe the current conditions (status) of springs vital signs (Table 6-1) 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, Seasonal Rank Sum tests for step trends in water quantity and water quality, and a dependent-samples sign test or paired Wilcoxon signed-rank test for endemic-plant data,
3. Use modeling and other data exploration techniques to evaluate potential explanatory variables and covariates over broad thematic and spatial scales, and
4. Evaluate the effectiveness of the sampling design using analyses of power to detect trends.

Status and trend reports are generated periodically for each park unit with springs monitoring. Data are 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 are 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).

Table 6-1. Reporting variables.

Vital sign	Reporting variables
Water quantity	Median and range of stage or flow Variance of stage or flow Length of flowing channel (up to 50 m)
Water quality	pH (median and range) Specific conductance (median and range) Temperature (median and range)
Endemic plants	Count classes and numeric counts (<500)

7 Personnel Requirements and Training

7.1 Roles and responsibilities

The NCPN hydrologist/aquatic ecologist organizes and oversees the springs monitoring program with assistance from the NCPN vegetation ecologist. The hydrologist acts as the project manager and is responsible for training the hydrological science technician, who is the primary hydrologic-data collector. The vegetation ecologist trains the biological science technician, who is the primary vegetation-data collector. Additional hydrological or biological science technicians may assist with data collection, entry, and verification. The project manager is responsible for data validation, as well as data summary, analysis, and reporting. The hydrologic technician assists with data summaries and annual briefs. The NCPN data manager coordinates data archiving, security, dissemination, and database design. The data manager, in collaboration with the project manager, also develops data-entry forms and other database features for quality assurance and data summary. The data manager is ultimately responsible for ensuring that adequate QA/QC procedures are built into the database and that appropriate data handling procedures are followed.

7.2 Qualifications

Lead hydrological science technician – The hydrological technician should have previous experience collecting flow measurements and using water quality multiparameter probes. Experience installing, using and maintaining water quantity monitoring equipment including staff gages, shallow groundwater wells, flow meters, flumes, and weirs is preferred. S/he should also be in good physical condition and be able to work independently in remote areas. Additional qualifications include experience using relational databases, spreadsheets, and word processing software, and creating data summaries.

Permanent or seasonal biological science technician – The field technician must have good botanical skills and preferably experience identifying wetland species of the Colorado Plateau. The field technician must have prior experience collecting vegetation data for long-term monitoring. Additional qualifications include attention to detail, good physical fitness, experience with backcountry work, and the ability to work independently.

Seasonal hydrologic technician (or intern or volunteer) – The field technician should have previous experience collecting water quantity and quality data, good physical fitness, the ability to troubleshoot electronic equipment, experience with backcountry work, and the ability to work independently.

7.3 Training

Prior to data collection, crews should become intimately familiar with all SOPs and park-specific materials, such as plant species lists and access documents. Each person should be trained in all protocol-specific data-collection methods within their assigned tasks (hydrology or vegetation), such that s/he can independently perform any necessary task. For field crew members involved in vegetation monitoring, the vegetation ecologist will provide training on appropriate plant species. Herbarium specimens and comparative notes on difficult or uncommon species will be provided for field observers. Observers should be tested on their ability to identify plant species, tailoring the test to more problematic species.

The lead hydrologic technician is responsible for ensuring that all crew members read and understand the NCPN and/or SEUG Backcountry Safety Plan prior to the field season. First aid, CPR, and vehicle safety will be covered during training each year. Each crew member must be proficient in the use of safety equipment, such as satellite phones and personal locator beacons, and is responsible for safeguarding him/herself at all times.

8 Operational Requirements

The annual workload for this protocol consists of field-data collection in March–November, data verification and validation in fall and winter, and data summary, analysis, and reporting in winter through summer.

Hydrological data are collected monthly for nine months at sentinel sites. Site condition, vegetation composition, endemic-plant counts, and repeat photographs are collected annually or at less frequent intervals during the growing season, between late May and early October. Repeat visits should be scheduled at approximately the same time each sampling year to maximize repeatability.

The NCPN fieldwork commitment is approximately 11 pay periods per year (880 person hours), including eight pay periods of hydrological work and three pay periods of hanging garden, vegetation composition, site characterization, and site condition work. SEUG continues a springs monitoring program that requires six pay periods of hydrological sampling per year. This affordable effort does not include additional time for data management, analysis, and reporting that is assumed to be a core part of year-round NCPN staff duties.

9 Revising the Protocol

Over time, methodological improvements, changes in available resources and expertise, and reassessments of the sampling design will result in revisions to this monitoring protocol. Specific revisions anticipated at time of writing included new technologies for monitoring site area at hanging gardens, estimates of variance and power analysis for vegetation sampling techniques, and the development of statistical models to integrate monitoring data.

Should the affordable effort increase or decrease the scope of this monitoring plan, the number of sampling sites can be increased or reduced accordingly. Sampling frequency can be changed within limits of the ability to detect long-term trends (either by reducing the number of samples or increasing the rest period between samples) and the role of automated dataloggers may be increased. Changes to the sampling design must be evaluated for their power to detect trends prior to being adopted.

This sampling protocol consists of a protocol narrative and 11 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 step-by-step instructions for performing each task. They are expected to be revised more frequently than the protocol narrative. Steps for changing the protocol narrative and SOPs are outlined in SOP #11.

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 narrative and each SOP contain a Revision History Log that should 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.

The NCPN uses a Master Version Table and Version Key Number to track which versions of the narrative and SOPs are used in each version of the monitoring protocol. The Version Key # is essential if project information is to be properly analyzed and interpreted. The protocol narrative, SOPs, and data should never be distributed independently of the Master Version Table.

10 Literature Cited

Beer, M., E. Nance, A. Wight, M. Powell, and R. DenBleyker. 2005. Northern Colorado Plateau Network data management plan. National Park Service, Northern Colorado Plateau Network, Moab, Utah.

Bryan, K. 1919. Classification of springs. Geology 28:522–561.

Crosbie, R. S., J. L. McCallum, G. R. Walker, and F. H. S. Chiew. 2012. Episodic recharge and climate change in the Murray-Darling Basin, Australia. Hydrogeology Journal 20:245–261.

Cudlip, L., K. Berghoff, and D. Vana-Miller. 1999. Water resources management plan: Arches National Park and Canyonlands National Park.

Dinger, E. C., A. E. Cohen, A. Hendrickson, and J. Marks. 2005. Aquatic invertebrates of Cuatro Ciénegas, Coahuila, México: Natives and exotics. Southwestern Naturalist 50:237–246.

Efron, B. 2013. Bayes' theorem in the 21st century. Science 340:1177–1178.

Ens, E-J., P. Cooke, R. Nadjamerrek, S. Namundja, V. Garingarr and D. Yibarbuk. 2010. Combining Aboriginal and non-Aboriginal knowledge to assess and manage feral water buffalo impacts on perennial freshwater springs of the Aboriginal-owned Arnhem Plateau, Australia. Environmental Management 45:751–758.

Erman, N. A. 2002. Lessons from a long-term study of springs and spring invertebrates (Sierra Nevada, California, U.S.A.) and implications for conservation and management. Proceedings of the Conference on Spring-fed Wetlands: Important Scientific and Cultural Resources of the Intermountain Region. http://www.wetlands.dri.edu.

Euliss, N. H., J. W. LaBaugh, L. H. Fredrickson, D. M. Mushet, M.K. Laubhan, G. A. Swanson, T. C. Winter, D. O. Rosenberry, and R. D. Nelson. 2004. The wetland continuum: A conceptual framework for interpreting biological studies. Wetlands 24:448–458.

Evenden, A., M. Miller, M. Beer, E. Nance, S. Daw, A. Wight, M. Estenson, and L. Cudlip. 2002. Northern Colorado Plateau Vital Signs Network and Prototype Cluster plan for natural resources monitoring: Phase I report, volume two, part three. National Park Service, Northern Colorado Plateau Network, Moab, Utah.

Field, S. A., A. J. Tyre, N. Jonzen, J. R. Rhodes, and H. P. Possingham. 2004. Minimizing the cost of environmental management decisions by optimizing statistical thresholds. Ecology Letters 7:669–675.

Fleishman, E., D. D. Murphy, and D. W. Sada. 2006. Effects of environmental heterogeneity and disturbance on the native and non-native flora of desert springs. Biological Invasions 8:1091–1101.

Foster, M., J. D. Stednick, and W. Rice. 2000. Inventory and characterization of upland water resources in Dinosaur National Monument. Colorado State University, Ft. Collins, Colorado.

Fowler, J. F. 1995. Biogeography of hanging gardens on the Colorado Plateau. Ph.D. dissertation. University of Wyoming, Laramie.

Freeze, R. A., and J. A. Cherry. 1979. Groundwater. Englewood Cliffs, N.J.: Prentice-Hall, Inc.

Grand Canyon Wildlands Council. 2002. Arizona Strip springs, seeps and natural ponds: Inventory, assessment and development of recovery priorities. Unpublished report to the Arizona Water Protection Fund. Flagstaff, Arizona.

Green, T. R., M. Taniguchi, H. Kooi, J. J. Gurdak, D. M. Allen, K. M. Hiscock, H. Treidel, and A. Aureli. 2011. Beneath the surface of global change: Impacts of climate change on groundwater. Journal of Hydrology 405:532–560.

Hackbarth, C., and R. Weissinger. 2013. Water quality in the Northern Colorado Plateau Network, water years 2010–2012. Natural Resource Technical Report NPS/NCPN/NRTR—2013/831. National Park Service, Fort Collins,

Colorado.

Hem, J. D. 1985. Study and interpretation of the chemical characteristics of natural water. U.S. Geological Survey Water-Supply Paper 2254. U.S. Geological Survey, Alexandria, Virginia.

Hendrickson, D. A., J. C. Marks, A. B. Moline, E. Dinger, and A. E. Cohen. 2008. Combining ecological research and conservation: A case study in Cuatro Cienagas, Coahuila, Mexico. Pages 127–157 *in* L. E. Stevens and V. J. Meretsky (eds.), Aridland Springs in North America: Ecology and Conservation. Tucson: University of Arizona Press.

Hershler, R., and D. W. Sada. 2002. Biogeography of Great Basin aquatic snails of the genus Pyrgulopsis. Smithsonian Contributions to the Earth Sciences 33:255–276.

Hubbs, C. 1995. Springs and spring runs as unique aquatic systems. Copeia 1995:989–991.

Huntoon, P. W. 1978. Feasibility of developing ground water supplies in Fossil Butte National Monument, Wyoming. University of Wyoming, Laramie.

Hurlow, H. A., and C. E. Bishop. 2003. Recharge areas and geologic controls for the Courthouse-Sevenmile spring system, western Arches National Park, Grand County, Utah. Special Study 108. Utah Geological Survey, Salt Lake City, Utah.

Kehrer, K. Jr. 1985. Water sources and developments in the North District of Capitol Reef National Park and closely surrounding areas. Capitol Reef National Park, Torrey, Utah.

Keleher, M. J., and R. B. Rader. 2008. Bioassessment of artesian springs in the Bonneville Basin, Utah, USA. Wetlands 28:1048–1059.

Kirby, S. 2007. Summary of ground-water sampling in the Courthouse Wash area, Grand County, Utah. Unpublished report from the Utah Geological Survey, Salt Lake City, Utah.

Klove, B., P. Ala-Aho, G. Bertrand, J. J. Gurdakf, H. Kupfersbergerg, J. Kværnerd, T. Muotka, H. Mykräc, E. Predah, P. Rossia, C. B. Uvoi, E. Velascof, and M. Pulido-Velazquez. 2014. Climate change impacts on groundwater and dependent ecosystems. Journal of Hydrology 518:250–266.

Kodric-Brown, A., and J. H. Brown. 2007. Native fishes, exotic mammals, and the conservation of desert springs. Frontiers in Ecology and Evolution 5:549–553.

Malanson, G. P., and J. Kay. 1980. Flood frequency and the assemblage of dispersal types in hanging gardens of the Narrows, Zion National Park, Utah. Great Basin Naturalist 40:365–371.

Marine, I. W. 1958. Groundwater resources of the Bryce Canyon National Park area, Utah. Geological Survey Ground Water Branch, Salt Lake City, Utah.

Masbruch, M. D., D. K. Solomon, and J. Harte. 2010. Groundwater age dating in and near Arches National Park, Utah. Unpublished report to National Park Service.

May, C. L., J. F. Fowler and N. L. Stanton. 1995. Geomorphology of the hanging gardens of the Colorado Plateau, in C. Van Riper, ed., Proceedings of the 2nd Biennial Conference on Research in Colorado Plateau National Parks. National Park Service Transactions and Proceedings Series NPS/NRNAU/NRTP-95/11.

McCallum, J. L., R. S. Crosbie, G. R. Walker, and W. R. Dawes. 2010. Impacts of climate change on groundwater in Australia: A sensitivity analysis of recharge. Hydrogeology Journal 18:1625–1638.

Meffe, G. K., and P. C. Marsh. 1982. Distribution of aquatic macroinvertebrates in three Sonoran Desert springbrooks. Journal of Arid Environments 6:363–371.

Meretsky, V. J. 2008. Mechanisms of change in seep/spring plant communities on the southern Colorado Plateau. Pages 211–229 *in* L. E. Stevens and V. J. Meretsky (eds.), Aridland Springs in North America: Ecology and Conservation. Tucson: University of Arizona Press.

Moran, M. 2011. Courthouse Wash–Seven Mile Canyon spring flow monitoring, Arches National Park, 2010 project update. Southeast Utah Group Natural Resource Program Report, Moab, Utah.

National Park Service–Water Resource Division (NPS-WRD). 2002. Recommendations for core water quality monitoring parameters and other key elements of the NPS Vital Signs Program water quality monitoring component. Freshwater Workgroup Subcommittee. Fort Collins, Colorado. 19 pp.

——. 2003. Baseline water quality data inventory and analysis: Arches National Park, volume I of II. Technical Report NPS/NRWRD/NRTR-2000/274. National Park Service, Washington, D.C.

Ng, G. C., D. McLaughlin, D. Entekhabi, and B. R. Scanlon. 2010. Probabilistic analysis of the effects of climate change on groundwater recharge. Water Resources Research 46:W07502.

Oberlin, G. E., J. P. Shannon, and D. W. Blinn. 1999. Watershed influence on the macroinvertebrate fauna of ten major tributaries of the Colorado River through Grand Canyon, Arizona. Southwestern Naturalist 44:17–30.

O'Dell, T., S. Garman, A. Evenden, M. Beer, E. Nance, D. Perry, and R. DenBleyker. 2005. Northern Colorado Plateau Inventory and Monitoring Network vital signs monitoring plan. National Park Service, Northern Colorado Plateau Network, Moab, Utah.

Patten, D. T., L. Rouse, and J. C. Stromberg. 2008. Isolated spring wetlands in the Great Basin and Mojave Deserts, USA: Potential response of vegetation to groundwater withdrawal. Environmental Management 41:398–413.

Perla, B. S., and L. E. Stevens. 2008. Biodiversity and productivity at an undisturbed spring in comparison with adjacent grazed riparian and upland habitats. Pages 230–243 *in* L. E. Stevens and V. J. Meretsky (eds.), Aridland springs in North America: Ecology and conservation. Tucson: University of Arizona Press.

Ponder, W. F. 2004. Desert springs of the Australian Great Artesian basin. Contributed paper in D. W. Sada and S. E. Sharpe, Conference proceedings, Spring-fed Wetlands: Important Scientific and Cultural Resources of the Intermountain Region, May 7–9, 2002, Las Vegas, NV. DHS Publication No. 41210. Retrieved from http://wetlands.dri.edu, April 24, 2017.

Pringle, C. M. 2000. Threats to U.S. public lands from cumulative hydrologic alterations outside of their boundaries. Ecological Applications 10:971–989.

Reynolds, J. H. 2012. An overview of statistical considerations in long-term monitoring. Pages 23–53 *in* R. A. Gitzen, J. J. Millspaugh, A. B. Cooper, and D. S. Licht (eds.), Design and analysis of long-term ecological monitoring studies. New York: Cambridge University Press.

Sabo, J. L., R. Sponseller, M. Dixon, K. Grade, T. Harms, J. Heffernan, A. Jani, G. Katz, C. Soykan, J. Watts, and J. Welter. 2005. Riparian zones increase regional species richness by harboring different, not more, species. Ecology 86:56–62.

Sada, D. W., E. Fleishman and D. D. Murphy. 2005. Associations among spring-dependent aquatic assemblages and environmental and land use gradients in a Mojave Desert mountain range. Diversity and Distributions 11:91–99.

Sada, D. W., and G. L. Vinyard. 2002. Anthropogenic changes in historical biogeography of Great Basin aquatic biota. Pages 277–293 *in* R. Hershler, D. B. Madsen, and D. Currey (eds.), Smithsonian Contributions to the Earth Sciences 33, Washington, D.C.

Sada, D. W., G. L. Vinyard, and R. Hershler. 1992. Environmental characteristics of small springs in northern Nevada (abstract). Page 76 *in* D. A. Hendrickson (ed.), Proceedings of the Twenty-third Annual Symposium of the Desert Fishes Council, Furnace Creek, CA, November 21–23, 1991. http://www.desertfishes.org/proceedings/DFC_Vol_XXII-XXIII.pdf.

Scanlon, B. R., D. G. Levitt, R. C. Reedy, K. E. Keese, and M. J. Sully. 2005. Ecological controls on water-cycle response to climate variability in deserts. Proceedings of the National Academy of Science 102:6033–6038.

Schelz, C., and M. Moran. 2004. Water quality monitoring, Arches National Park, 1994–2004. General Technical Report SEUG-005-2004. National Park Service, Moab, Utah.

——. 2005a. Water quality monitoring, Canyonlands National Park, 1994–2004. General Technical Report SEUG-003-2005. National Park Service, Moab, Utah.

——. 2005b. Water quality monitoring, Hovenweep National Monument, 1999–2004. General Technical Report SEUG-001-2005. National Park Service, Moab, Utah.

Seager, R., M. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H. Huang, N. Harnik, A. Leetmaa, N. Lau, C. Li, J. Velez, and N. Naik. 2007. Model projections of an imminent transition to a more arid climate in southwestern North America. *Science* 316:1181–1184.

Seager, R., M. Ting, C. Li, N. Naik, B. Cook, J. Nakamura, and H. Liu. 2013. Projections of declining surface-water availability for the southwestern United States. Nature Climate Change 3:482–486.

Shepard, W. D. 1993. Desert springs-both rare and endangered. Aquatic Conservation: Marine and Freshwater Ecosystems 3:351–359.

Skagen, S. K., C. P. Melcher, W. H. Howe, and F. L. Knopf. 1998. Comparative use of riparian corridors and oases by migrating birds in southeast Arizona. *Conservation Biology* 12:896–909.

Spence, J. 2008. Spring-supported vegetation along the Colorado River on the Colorado Plateau: Floristic, vegetation structure and environment. Pages 185–210 *in* L. E. Stevens and V. J. Meretsky (eds.), Aridland Springs in North America: Ecology and Conservation. Tucson: University of Arizona Press.

Spence, J. R., and N. R. Henderson. 1993. Tinaja and hanging garden vegetation of Capitol Reef National Park, southern Utah, U.S.A. Journal of Arid Environments 24:21–36.

Springer, A. E., and L. E. Stevens. 2009. Spheres of discharge of springs. Hydrogeology 17:83–93.

Springer, A., L. Stevens, and R. Harms. 2006. Inventory and classification of selected National Park Service springs on the Colorado Plateau. Final report for NPS Cooperative Agreement CA 1200-99-009. Northern Arizona University, Flagstaff, Arizona.

Stevens, L. E., and A. E. Springer. 2004. A conceptual model of springs ecosystem ecology. Task 1B final report NPS cooperative agreement #1200-99-009. Northern Arizona University, Flagstaff, Arizona.

Stohlgren, T. J., D. Binkley, G. W. Chong, M. A. Kalkhan, L. D. Schell, K. A. Bull, Y. Otsuki, G. Newman, M. Bashkin, and T. Son. 1999. Exotic plant species invade hot spots of native plant diversity. Ecological Monographs 69:25–46.

Strohbach, M., V. Audorff, and C. Beierkuhnlein. 2009. Drivers of plant species composition in siliceous spring ecosystems: Groundwater chemistry, catchment traits or spatial factors? Journal of Limnology 68:375–384.

Stumpf, S. E. 2007. Community level effects of a evolutionary novel keystone invader (Orconectes virilis) on arid stream ecosystems. MS thesis. Northern Arizona University, Flagstaff, Arizona.

Sumsion, C. T. 1967. Water resources of Cedar Breaks National Monument, Iron County, Utah. U.S. Geological Survey, Salt Lake City, Utah.

Thoma, D., D. Sharrow, K. Wynn, J. Brown, M. Beer, and H. Thomas. 2009. Water quality vital signs monitoring protocol for park units in the Northern Colorado Plateau Network. National Park Service, Moab, Utah.

Unmack, P. J. and W. L. Minckley. 2008. The demise of desert springs. Pp. 11-34 in L. E. Stevens and V. J. Meretsky (eds.), Aridland Springs in North America: Ecology and Conservation. Tucson: University of Arizona Press.

U.S. Department of Agriculture Forest Service (USDA-FS). 2012. Groundwater dependent ecosystems: Level II inventory field guide. General Technical Report WO-86b. U.S. Department of Agriculture, Washington, D.C.

Van Grinsven, M., D. Thoma, M. Malick, and M. Moran. 2010. Water quality in the Northern Colorado Plateau Network, 2006–2009. Natural Resource Technical Report NPS/NCPN/NRTR—2010/358. National Park Service, Fort Collins, Colorado.

Vinson, M. R., and E. C. Dinger. 2008. Aquatic invertebrates of the Grand Staircase-Escalante National Monument, Utah. The Southwestern Naturalist 53:374–384.

Weissinger, R. 2022. Evaluation of hanging-garden endemic-plant monitoring at Southeast Utah Group national parks, 2013–2020. Natural Resource Report NPS/NCPN/NRR— 2022/2473. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/2294.

Weissinger, R., E. Jensen, and A. Wight. 2011. Status of rare endemic plant species in selected habitats in Arches National Park and Natural Bridges National Monument. Natural Resource Technical Report NPS/NCPN/NRTR—2011/443. National Park Service, Ft. Collins, Colorado.

Weissinger, R., and M. Moran. 2013. Proposed sampling design for springs, seeps, and hanging gardens monitoring in the Northern Colorado Plateau Network. Natural Resource Report NPS/NCPN/NRR—2013/618. National Park Service, Fort Collins, Colorado.

Weissinger, R., D. Perkins, and E. Dinger. 2012. Biodiversity, water chemistry, physical characteristics, and anthropogenic disturbance gradients of sandstone springs on the Colorado Plateau. Western North American Naturalist 72(3):393–406.

Weissinger, R., M. Moran, S. Monroe, and H. Thomas. 2017. Springs and seeps monitoring protocol for the park units in the Northern Colorado Plateau Network, v.1.00. Natural Resource Report NPS/ NCPN/NRR—2017/1439. National Park Service, Fort Collins, Colorado.

Weissinger, R., D. Thoma, K. Dahlin, and K. Keteles. 2013. Screening for contaminants of emerging concern in the Northern Colorado Plateau Network, 2010 and 2012. Natural Resource Technical Report NPS/NCPN/NRTR—2013/802. National Park Service, Fort Collins, Colorado.

Weissinger, R., D. Witwicki, H. Thomas, M. Van Grinsven, A. Wight, M. Scott, and E. Peltz. 2016. Integrated riparian monitoring protocol for the park units in the Northern Colorado Plateau Network. National Park Service, Moab, Utah.

Welsh, S. L., N. D. Atwood, S. Goodrich, and L. C. Higgins. 2003. A Utah Flora, 3rd edition. Provo, Ut.: Brigham Young University.

Welsh, S. L., and C. A. Toft. 1981. Biotic communities of hanging gardens in southeastern Utah. National Geographic Society Research Reports 13:663–681.

Woodward, A. 2004. Temporal sampling frames: Summary of a workshop. U.S. Geological Survey Forest and Rangeland Ecosystem Science Center, Olympic Field Station, Park Avenue, Port Angeles, Washington.

Appendix A. Summary of Parameters Collected During NCPN Springs Monitoring

Table A-1. Site characterization.

Parameter	Units	Description	Frequency taken	SOP
Aspect	degrees	dominant aspect of spring as taken from center of orifice area	once	3
Slope	degrees	dominant slope of spring's dominant geomorphic surface	once	3
Slope variability	-	high, medium, or low	once	3
Potential solar radiation	%	percent of available solar radiation that reaches the spring orifice based on site topography and aspect	once	3
Spring type	-	picklist from Springer and Stevens (2008)	once	3
Aquifer geology	-	picklist from geologic maps	once	3
Measured size	m^2	overall area based on measurements taken during site mapping	whenever site map is made	3
Multiple orifices	-	yes/no within 200 m	once	3
Other springs nearby	-	yes/no between 200 m and 0.8 km	once	3
Number of channels	-	count	whenever site map is made	3
Channel length	m	spring-fed stream up to 50 m	annually	3, 6
Channel type	-	spring-dominated, run-off dominated, mixed geomorphology	once	3
Spring orifice description	-	text	whenever site map is made	3
Channel description	-	text	whenever site map is made	3
Site map	-	sketch map including geomorphic surfaces, water quality and water quantity measurement locations, photopoint locations, map scale, and north orientation	site establishment, after significant change, at management request	4

Table A-2. Vegetation composition.

Parameter	Units	Description	Frequency taken	SOP
Vegetation	%	cover class for each species by geomorphic surface	annually	4
Endemic plants	-	count by species for backwall, colluvial slope, alcove	annually	7

Table A-3. Water quantity.

Parameter	Units	Description	Frequency taken	SOP
Air temperature	°C	air temperature in shade	monthly	5
Current conditions	-	precipitation by category	monthly	5
Cloud cover	%	-	monthly	5
Prior precipitation	-	estimated dates and amount in previous week based on local weather station records	monthly	5
Flow severity	-	dry, no flow, normal, flood	monthly	5
Measurable discharge	-	yes/no	monthly	5
Volumetric flow measurement	ml/sec	time to fill known volume container; minimum 5 measurements	monthly	5
Pool surface elevation	m	distance from reference point to water's surface	monthly	5
Piezometer depth to water	m	distance from top of piezometer casing to water's surface; minimum 3 measurements	monthly	5
Piezometer depth to ground	m	distance from top of piezometer casing to ground surface	monthly	5

Table A-4. Water quality.

Parameter	Units	Description	Frequency taken	SOP
Estimate of mixing	-	well, moderately well, poorly	monthly	5
Measurements taken	-	yes/no	monthly	5
Water quality instrument	-	make and model	monthly	5
Calibration date	-	date	monthly	5
Calibration time	-	time	monthly	5
Calibration location	-	on site, in office, at previous site, etc.	monthly	5
pH calibration	-	pre-calibration reading, water temperature, post-calibration reading	monthly	5
Specific conductance calibration	µS/cm at 25°C	pre-calibration reading, water temperature, post-calibration reading	monthly	5
pH	-	minimum 3 measurements over 3 minutes	monthly	5
Specific conductance	µS/cm at 25°C	minimum 3 measurements over 3 minutes	monthly	5
Water temperature	°C	minimum 3 measurements over 3 minutes	monthly	5
Major disturbance	-	yes/no; describe; prompts new sketch map	monthly	5
Bacteria taken	-	yes/no	at management request	5
Bacteria credibility checks	-	sample temperature, holding period, incubation time, incubation temperature	at management request	5
Total coliforms	MPN/ 100 ml	IDEXX Colilert method	at management request	5
Eschericia coli	MPN/ 100 ml	IDEXX Colilert method	at management request	5

Table A-5. Site condition.

Parameter	Units	Description	Frequency taken	SOP
Repeat photos	-	repeat photos from permanent photopoints	annually	6
Amphibians	-	present/not observed, list species	annually	6
Fish	-	present/not observed, list species	annually	6
Exotic plants	-	present/not observed, list species	annually	6
Crayfish	-	present/not observed	annually	6
Flow modification	-	present/absent from picklist	annually	6
Flow modification active	-	yes/no	annually	6
Flow affected	%	if flow modification is active	annually	6
Erosion	%	cover class for each category for each surface	annually	6
Disturbance at spring	%	cover class for each category for each surface	annually	6
Disturbance around spring	-	present/absent from picklist for surrounding area	annually	6

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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