



Proposed Sampling Design for Springs, Seeps, and Hanging Gardens Monitoring in the Northern Colorado Plateau Network

Natural Resource Report NPS/NCPN/NRR—2013/618



ON THE COVER

Monitoring the outflow of a hanging garden, Natural Bridges National Monument. NPS photo.

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1 Introduction

1.1 Background

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 Natural Resource Inventory and Monitoring (I&M) Program 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, southwestern Wyoming, and northern Arizona.

In 2003, NCPN staff solicited input on natural resources of concern and ecosystem indicators, known as “vital signs,” from more than one hundred NPS staff and regional and national experts (O’Dell et al. 2005). Potential vital signs were evaluated for management significance and utility, ecological significance, scientific validity, feasibility and cost of implementation, and signal-to-noise ratio. Because of the scarcity of water on the Colorado Plateau and its disproportionately high use by flora and fauna, springs and seeps were quickly identified as an ecosystem of concern for the NCPN.

After a set of network-wide vital signs were chosen, park managers were asked to select their top priorities for monitoring. Four parks identified springs and seeps monitoring as one of their highest priorities: Arches National Park (NP), Canyonlands NP, Hovenweep National Monument (NM), and Natural Bridges NM. This report describes the proposed sampling design for springs monitoring at these four parks, all of which are managed by the NPS Southeast Utah Group (SEUG). It also details our ability to detect a specified trend in annual median flow under various sampling frequencies using a power analysis of pilot data, defines the affordable effort for NCPN monitoring, and details sample site selection and a revisit strategy to meet monitoring goals.

1.2 Monitoring indicators

Three indicators were selected for springs and seeps monitoring: (1) water quantity, (2) water chemistry, and (3) vegetation species composition, with an emphasis on rare plants at hanging gardens. All monitoring indicators have natural variability and observation bias.

This report focuses primarily on water quantity because monthly sampling data were available for analysis. Shifts in the persistence and timing of surface water are important, but cannot be assessed with the pilot data available. The sampling design for flow monitoring will need to be reassessed after a record of continuous monitoring data is available. Water chemistry and vegetation methods will also need to be assessed for their ability to detect trends in the future.

2 Water Quantity Pilot Data

The Southeast Utah Group initiated monthly water-quality sampling in the early 1980s and added reliable water quantity measurements at several spring sites in the early 2000s (Schelz and Moran 2004, 2005a, 2005b). In a separate study, monthly spring flow monitoring began at four sites in Arches National Park in 2001 (Moran 2011). SEUG staff provided these data to the NCPN for use in estimating background variability in flow at springs (Table 2-1). While not all of the proposed NCPN monitoring sites are represented in this dataset, the variability is assumed to be representative of the sampling sites as a whole.

Natural variability in geomorphic setting and site stability is expected to affect the variability of a site's dataset. Sampling locations that are naturally protected from flooding (e.g., many alcove and hanging-garden sites) or situated at bedrock pourovers are considered to be stable and relatively permanent. Moderately stable sites experience minimal flooding or downcutting based on their geomorphic setting, and sampling locations may need to be infrequently relocated (every five years or so). Unstable sites are subject to frequent flooding and are geomorphically active; sampling locations must be relocated on a regular basis, sometimes from month to month.

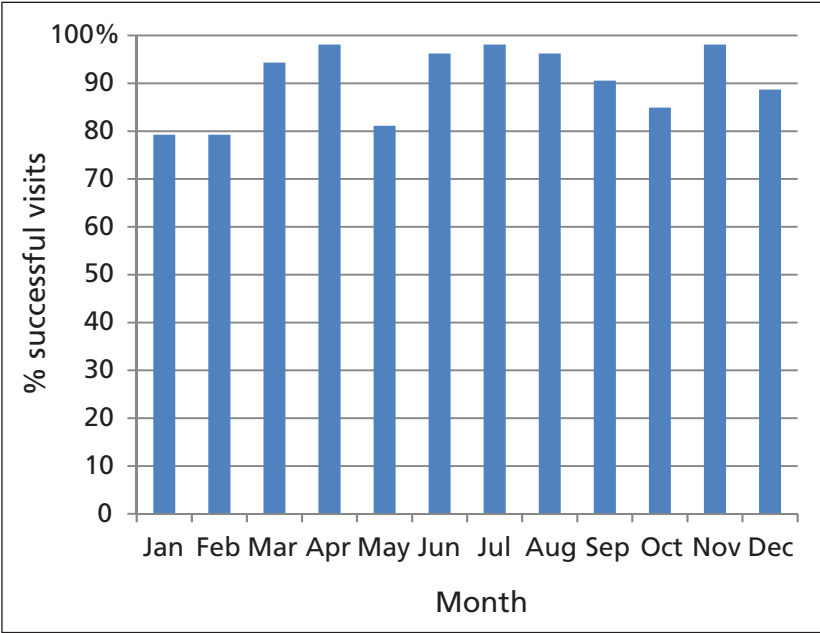


Figure 2-1. Percent successful site visits by month from all datasets used in the power analyses (n=53 for each month).

Over varying numbers of years (see Table 2-1) at nine sites, the number of possible monthly visits was 53. The percentage of successful site visits conducted each month ranged from 79 to 98% (Figure 2-1). January, February, May, and October had the highest incidences of missing data. Missed samples in winter months generally occurred due to weather and access issues. Missing data from spring and fall were generally the result of personnel shortages during busy field

Table 2-1. Spring sampling sites with >3 years of monthly flow data provided by the Southeast Utah Group.

Site name	Geomorphic setting	Site stability	Years of data record used
Arches NP			
Courthouse Wash near Moab	Wash bottom	Stable	2004–2008
Poison Ivy Spring	Hanging garden outflow	Moderately stable	2001–2010
Sevenmile Boundary Spring	Hanging garden outflow	Stable	2001–2010
Sleepy Hollow Spring	Hanging garden outflow	Moderately stable	2001–2010
Courthouse Boundary Spring	Wash bottom	Unstable	November 2005–2010
Canyonlands NP			
Salt Creek near Crescent Arch	Wash bottom	Unstable	2007–2010
Little Spring	Wash bottom	Moderately stable	2002–2003, 2005–2006, 2008–2009
Hovenweep NM			
Hackberry Spring	Alcove	Stable	2004–2007, 2009–2010
Square Tower Spring	Alcove	Stable	2004–2007, 2009–2010

seasons. Equipment failure also caused cancellation of some site visits.

2.1 Trend analysis

The presence of trend was investigated for each dataset using the seasonal Kendall tau test at $\alpha=0.05$ using TimeTrends 3.0 freeware (available at <http://www.niwa.co.nz/our-science/freshwater/tools/time-trends>). The non-parametric seasonal Kendall tau test for monotonic trends in data that have seasonal response patterns (Hirsch et al. 1982) has become widely used for periodically sampled water quality and flow data (Helsel et al. 2005).

Of the nine sites tested for trends, three showed a significant decline, all at Arches NP. Those three datasets were then fitted with a non-parametric equivalent of a regression line called a Sen slope, which is calculated as the median annual slope of all possible pairs for a season (TimeTrends 3.0). This slope corresponds to the estimated median annual decline in water quantity, and the percent annual decline was calculated as (median annual Sen slope/median annual value) $\times$ 100. Percent decline for the data record was estimated using the Sen slope intercepts from the beginning (x_0) and end (x_n) of the data record, where n is the period of record in years using the formula:

$$\frac{(x_0 - x_n) \times 100}{n}$$

Over the 10-year record, Poison Ivy Spring showed an estimated decline of 0.12 gallons per minute (gpm) annually, corresponding to an annual decline of 4.84% ($S=-208$, $p < 0.0001$; Figure 2-2). Overall, flow decreased approximately 37%, from roughly 3 gpm to 1.9 gpm. (An anomaly in mid-2006 corresponded with relocation of the sampling site due to changes in the channel. However, the overall downward trend in the data is apparent even with this step considered.)

Sevenmile Boundary Spring decreased an estimated 0.43 gpm annually, at a rate of 7.14% ($S=-406$, $p < 0.0001$; Figure 2-3). Over the 10-year record, flow decreased from roughly 8.5 gpm to 3.8 gpm, or about 55%.

The third site with a significant decline was Courthouse Boundary Spring. The decline followed a step trend corresponding to a

flood in October 2005. Before this flood, the sampling location was a stable bedrock outcrop, and there was no trend in the dataset (May 2001–September 2005; data not shown). After the flood, the outcrop was buried in sediment and the sampling location was frequently relocated due to changes in the channel. An additional large flood occurred in October 2006, and periodic bank collapses continue to occur.

It is difficult to say if the post-flood trend is “real” or a result of sampling variability. The decline was estimated at 0.87 gpm annually, or 8.28% ($S = -43$, $p < 0.0001$; Figure 2-4). The total decline was 51% over five years, (November 2005–December 2010), from about 10.57 gpm to about 5.23 gpm. The power analysis in this report used the post-2005 flood dataset, rather than the more stable pre-2005 flood data, because it more accurately reflects current sampling conditions at the site.

2.2 Power analysis

Power analysis is a means of quantifying the confidence with which a sampling scenario can detect a specified effect, given that the effect actually exists (Quinn and Keough 2002). In statistical terms, power analysis estimates the probability of *not* making a Type II error (false negative). It is useful for assessing the impact of natural and sampling-based parameter variability on the ability to detect trends in that parameter. When used appropriately, power analysis can assist in developing an efficient, sensitive monitoring program by tailoring sample sizes and frequencies to meet stated monitoring objectives within the limitations of the affordable sampling effort.

The utility of power analysis has been questioned, however, especially considering that most ecological data fail to meet standard assumptions implicit in the parametric tests used in widely available power analysis software (e.g., Fox 2001; Morrison 2007). Alternative power-analysis methods based on more applicable tests have been developed as a response to such criticisms. Irvine and others (2012) developed a power analysis for water-quality data based on repeated iterations of the seasonal Kendall test using pilot data representative of future sampling conditions. A user can deseasonalize data by

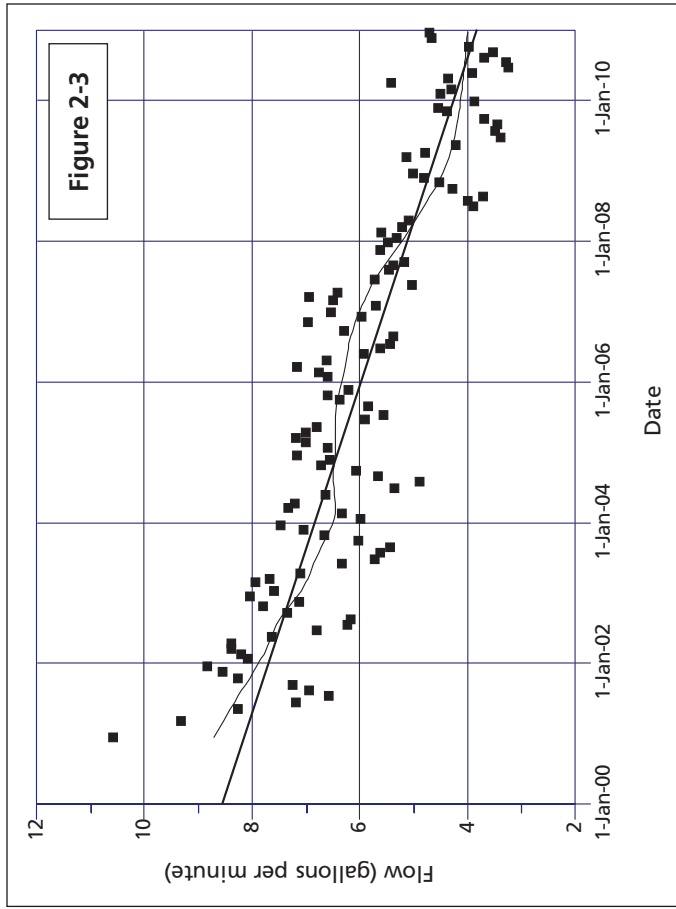
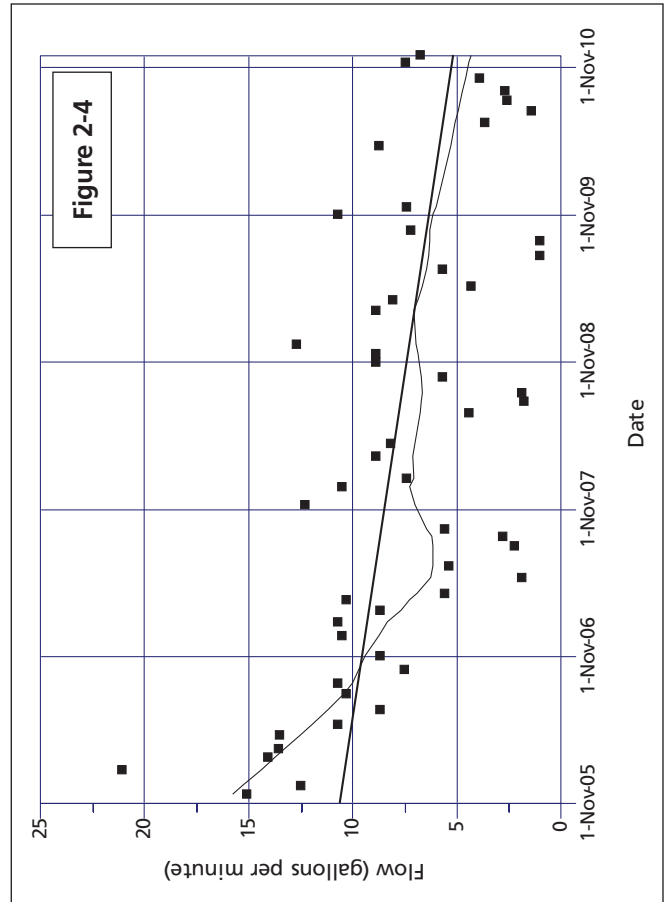
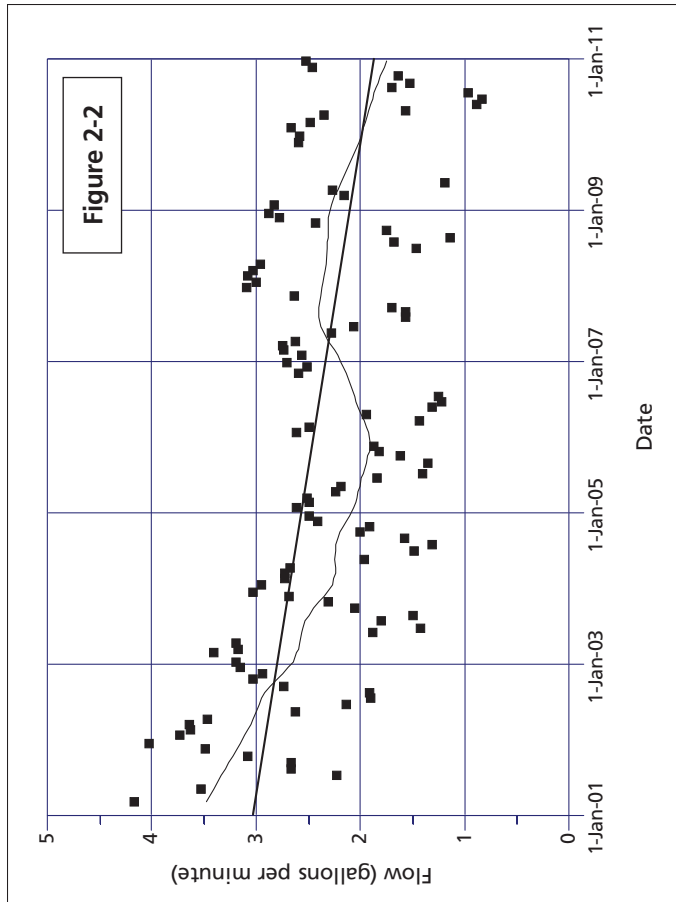


Figure 2-2. Dataset with Sen slope (fitted trend line) and LOWESS smoothed line for Poison Ivy Spring, Arches National Park, 2001–2010.

Figure 2-3. Dataset with Sen slope (fitted trend line) and LOWESS smoothed line for Sevenmile Boundary, Arches National Park, 2001–2010.

Figure 2-4. Dataset with Sen slope (fitted trend line) and LOWESS smoothed line for Courthouse Boundary, Arches National Park, November 2005–2010.

For all figures, the period of locally weighted regression used in the LOWESS was the nearest 30% of data surrounding each point.

creating residuals from the monthly median, then randomizing the residuals within months and across years. We modified the R code presented by Irvine and others (2012) to fit the number of seasons in our datasets. Power analysis tests were conducted using R 2.10.0 freeware (R Core Development Team 2009).

Power analysis can only be used to estimate the power of the sampling strategy used in the pilot dataset; in this case, each spring was sampled monthly at most and in a stable or unstable location. The results assume that the same sampling schedule and location will be followed in the future. Each spring is considered to be a unique site; that is, there are no replicates other than repeat sampling over time. Power analysis examines data variability over multiple sampling events and requires a minimum of three sampling events for analysis. Some sites with a shorter period of record did not have three records for each month. Months with zero or one record for a particular site were not included in the power analysis.

2.2.1 Parameters and sampling scenarios

Any decline in water quantity can potentially alter spring habitat and function, but biologically meaningful thresholds are difficult to establish. Datasets were tested for 80% power ($\beta = 0.2$) at $\alpha = 0.1$ for arbitrarily selected annual change rates of 2.5% and 5% in median flow. A 2.5% annual rate of decline corresponded to a cumulative 12% decline in median flow over 5 years and 22% decline over 10 years. A 5% annual rate of decline corresponded to a cumulative 23% decline in median flow over 5 years and 40% decline over 10 years. These rates of change were less dramatic than declines in flow already noted at three sites with a 10-year data record.

Five flow sampling scenarios were tested:

1. Monthly,
2. Monthly with no winter sampling (Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov),
3. Bi-monthly (Feb, Apr, Jun, Aug, Oct, Dec),
4. Quarterly (Mar, Jun, Sep, Dec), and

5. Capturing the low-flow time period when evapotranspiration is highest (Jun, Jul, Aug, Sep).

Monthly sampling was the maximum sampling effort testable using this pilot dataset. Potential sampling scenarios tested in the power analysis were designed to avoid months with the most missing data during the past 10 years of sampling, because it is presumed that they will also be the hardest months to sample in the future.

The “no-winter” sampling scenario minimizes missed samples due to winter weather conditions. Bi-monthly and quarterly sampling would allow more sites to be visited without exceeding the affordable effort (see Section 4.1). A low-flow sampling regime was tested because minimum flows have the greatest impact on biological organisms, as limited water quantities also limit the extent and quality of available habitat at a spring. Focusing sampling on summer months, therefore, may be a useful method of assessing spring ecosystem function from a biotic perspective. However, biotic activity also adds noise to flow data through local and variable reductions in flow via evapotranspiration. Sampling that includes the dormant season could allow more direct comparisons of available water quantity over time.

2.2.2 Use of trended data

Because the presence of a trend increases the sampled variability of the dataset and therefore can artificially inflate the number of years required to achieve a specified power in a power analysis, an attempt was made to detrend the data when necessary. Because Sen slope equations are not produced by TimeTrends 3.0 software, the data could not be detrended using this more appropriate method. Moreover, linear regressions were a poor fit for our non-parametric datasets, resulting in large residuals, and these analyses were much slower to achieve the desired power than when the trended data were used. As such, power estimates presented here for the three sites discussed above used the trended data and should be understood to be more conservative than necessary; that is, the true ability to detect the specified trend should be achieved more quickly than what is presented.

2.2.3 Results

Results reported according to the sampling year in which 80% power is surpassed; that is, the year when a better-than-80% likelihood of not obtaining a false negative result using a seasonal Kendall tau test (i.e., not detecting a trend in annual median flow when in fact, a trend exists) would be achieved. Monthly, no-winter, bi-monthly, quarterly, and low-flow sampling scenarios are presented for springs representing a variety of geomorphic settings (Table 2-2).

Monthly sampling would detect a 5% change in median flow at most sites within five years, a level of change that has already been documented or surpassed for several sites at Arches NP. No-winter, bimonthly, or quarterly sampling regimes would detect a 5% trend in median flow at most sites within six years.

2.2.4 Interpretation

As expected, the power to detect trend in median flow generally increased with sam-

pling frequency. The same pattern was noticeable in some sites using the no-winter (9 samples), bi-monthly (6 samples), and quarterly (4 samples) strategies but, surprisingly, these sampling frequencies often performed about equally, especially at the 5% change level. The low-flow sampling strategy included the same number of samples as quarterly sampling, but generally performed much worse in achieving 80% power to detect a trend. This result was likely due to the presence of no-flow data in the datasets, when sites had pooled surface water present but no measurable flow. In these cases, the sampling methods could not distinguish between differences in available water quantity and were therefore censored for detecting trends below a certain site-specific threshold. While the duration of no-flow events is of considerable biological interest for springs monitoring, they appear to complicate the hydrologic sampling tested here and cannot be adequately estimated with this dataset.

Table 2-2. Years to surpass 80% power to detect a 2.5% and 5% change in median annual flow at $\alpha = 0.1$.

Site	Monthly (12)		No-winter (9)		Bimonthly (6)		Quarterly (4)		Low-flow (4)	
	2.5%	5%	2.5%	5%	2.5%	5%	2.5%	5%	2.5%	5%
Wash Bottoms										
Courthouse Wash near Moab	5	5	6	6	7	6	8	6	10	9
Courthouse Boundary	(5)	(4)	(6)	(5)	(6)	(5)	(8)	(6)	(10)	(8)
Salt Creek near Crescent Arch	6 ^{*10}	5	5	5	7 ^{*5}	7 ^{*5}	8	8	>10	>10
Little Spring	5 ^{*9}	4	5	4	6 ^{*5}	6 ^{*5}	7 ^{*3}	6 ^{*3}	8	7
Hanging Garden Outflow										
Poison Ivy	(6)	(6)	(7)	(6)	(8)	(6)	(9)	(6)	(10)	(9)
Sevenmile Boundary	(6)	(5)	(7)	(5)	(8)	(6)	(10)	(7)	(9)	(6)
Sleepy Hollow	4	4	5	4	5	4	6	4	8	5
Alcoves										
Hackberry	3	3	3	3	3	3	3	3	3	3
Square Tower	3	3	3	3	3	3	3	3	3	3

The number of presumed subsamples per year is indicated in parentheses after each sampling scenario. Datasets with missing seasons are indicated by a *, and the number of seasons actually included in the analysis follows the asterisk. Trended datasets (n = 3 sites) are bolded and in parentheses.

3 Sample Site Selection

3.1 Sentinel sites

The objective of NCPN springs monitoring is to determine status and trends at specific sites, not to make inference to other sites. Springs are highly complex ecosystems that naturally vary in water quantity, water chemistry, topographic setting, aquifer age, 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 a random sample of sites. By using selectively chosen springs that are of management interest, known as sentinel sites, instead of a random sample of springs, we acknowledge that trends detected at our sites may be unrepresentative of regional trends as a whole (Edwards 1998).

The Southeast Utah Group selected sentinel monitoring sites according to 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 of park boundaries, and surrounding agricultural and extractive land uses.

In Arches NP, proposed sampling sites are clustered in the northern sections of Courthouse Wash and Salt Wash within park boundaries (Figure 3-1; figures start on page

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

Site name	Spring type
Arches National Park	
Lost Spring	Hanging garden with pool
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	Wash bottom stream
Canyonlands National Park (Island in the Sky)	
Alcove Spring	Hanging garden
Cabin Spring	Stream
Holeman Spring	Hanging garden with outflow
Neck Spring	Hanging garden
Syncline Loop	Hanging garden with outflow
Canyonlands National Park (Needles)	
Big Spring	Hanging garden with pool
Kirk's Cabin	Wash bottom stream
Little Spring	Wash bottom stream
Hovenweep National Monument	
Goodman Point	Stream
Hackberry House	Alcove with pool
Square Tower Spring	Alcove with pool
Natural Bridges National Monument	
Upper Armstrong Spring	Hanging garden with outflow

*Site is outside NPS boundaries.

11). 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 all have a 10-year flow data record from SEUG sampling, and SEUG plans to continue monitoring flow for at least three of these sites on a monthly basis. The NCPN will augment this sampling by adding site characterization, water chemistry, 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 sites are to be initiated by the NCPN.

Canyonlands National Park (Figure 3-2) has fewer known direct threats to proposed monitoring sites than Arches NP. 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 and site area, but not flow. The White Rim sandstone contains many small hanging gardens, but a reconnaissance of accessible areas determined that none were suitable for monitoring, primarily due to access and a lack of a stable flow monitoring location.

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 to monitor water quantity at Square Tower Spring, and the NCPN will augment this site with vegetation and site characterization data.

There are few flowing springs at Natural Bridges National Monument, except for where groundwater intersects 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.

3.2 Randomly sampled populations

Exceptions to the sentinel-site approach occur at hanging gardens in Arches National Park and Natural Bridges National Monu-

ment. Hydrogeologic studies suggest that these hanging gardens 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 can be expected to react similarly to climate and precipitation events. For climate-change monitoring purposes, hanging gardens emerging from the same geologic formation in the same watershed represent one population and will be sampled using a random subsample. 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). Because 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, specific sites there were selected to be monitored as sentinel sites (see above). 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). Courthouse Wash has 29 known locations, Upper Salt Wash has 20, and the Freshwater Canyon/Delicate Arch area has 23. Hanging gardens at Natural Bridges NM are considered one population, with 19 documented locations (Figure 3-4). Upper Armstrong Spring, discussed above, became 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 will be sampled in the randomly generated order until the affordable sampling effort is reached. Additional power analyses will be necessary in the future to determine an appropriate sample size for detecting trends in site area and vegetation measures.

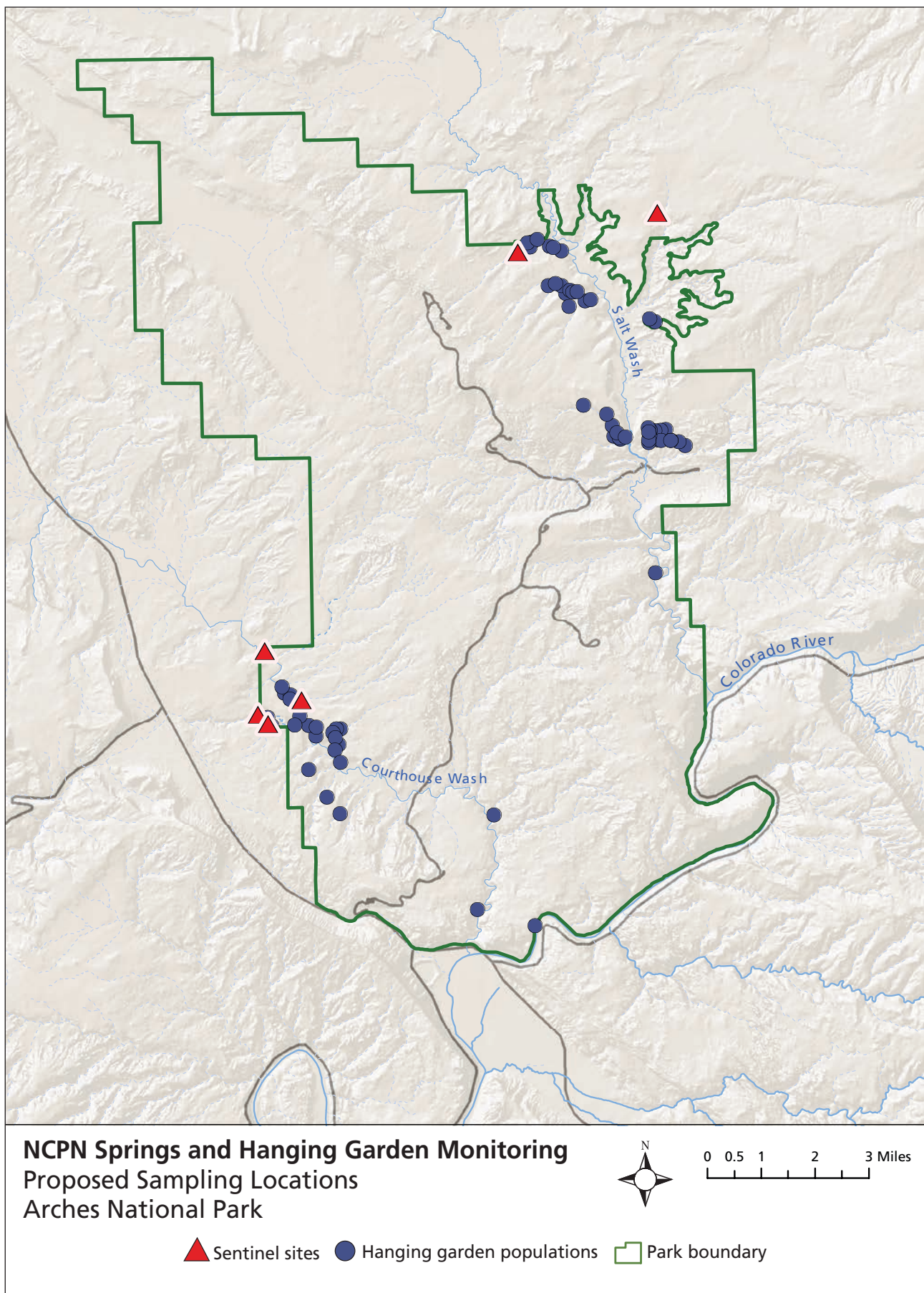


Figure 3-1. Locations of sentinel monitoring sites and hanging gardens for random sampling at Arches National Park.

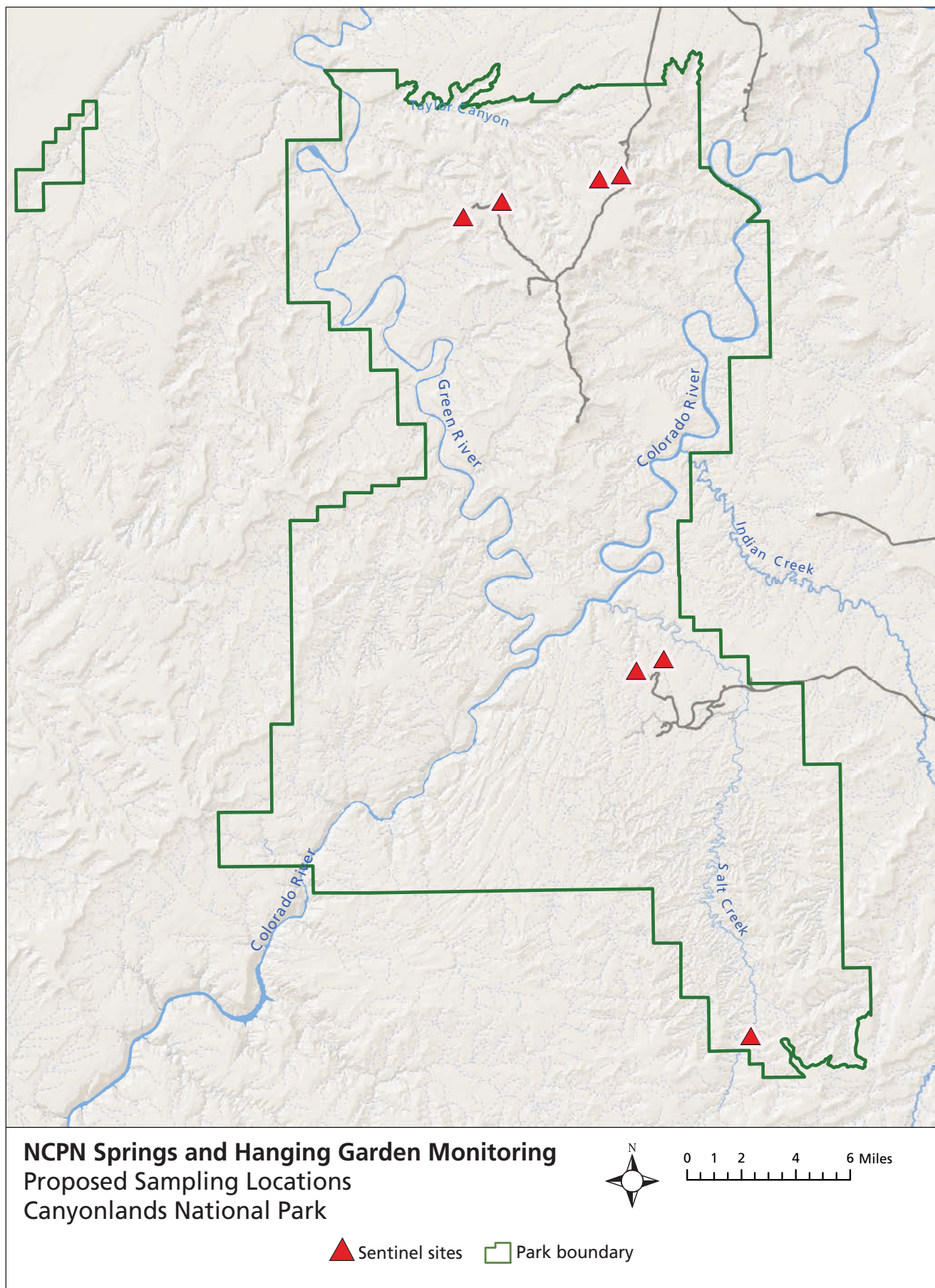


Figure 3-2. Locations of sentinel monitoring sites at Canyonlands National Park.

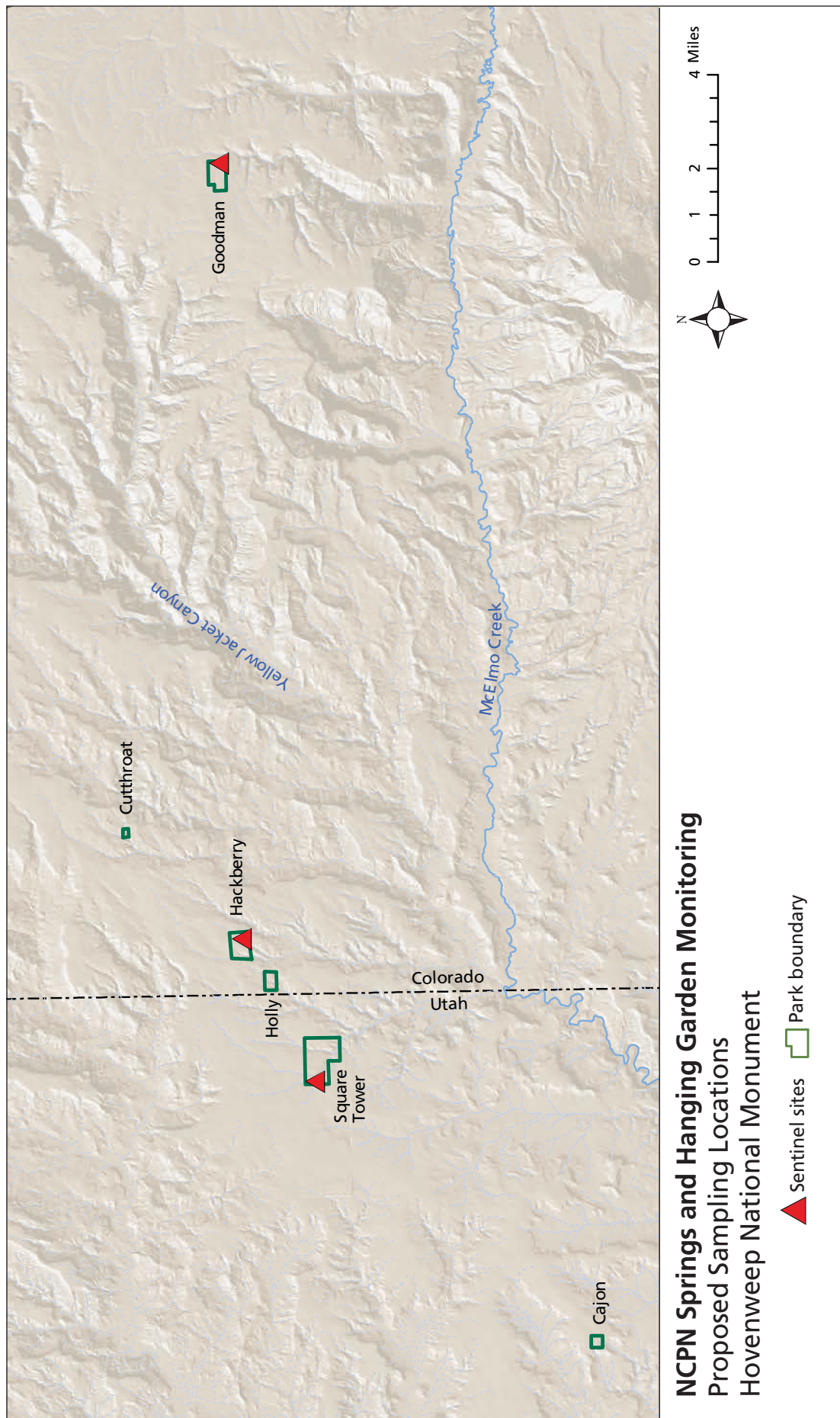


Figure 3-3. Locations of sentinel monitoring sites at Hovenweep National Monument.

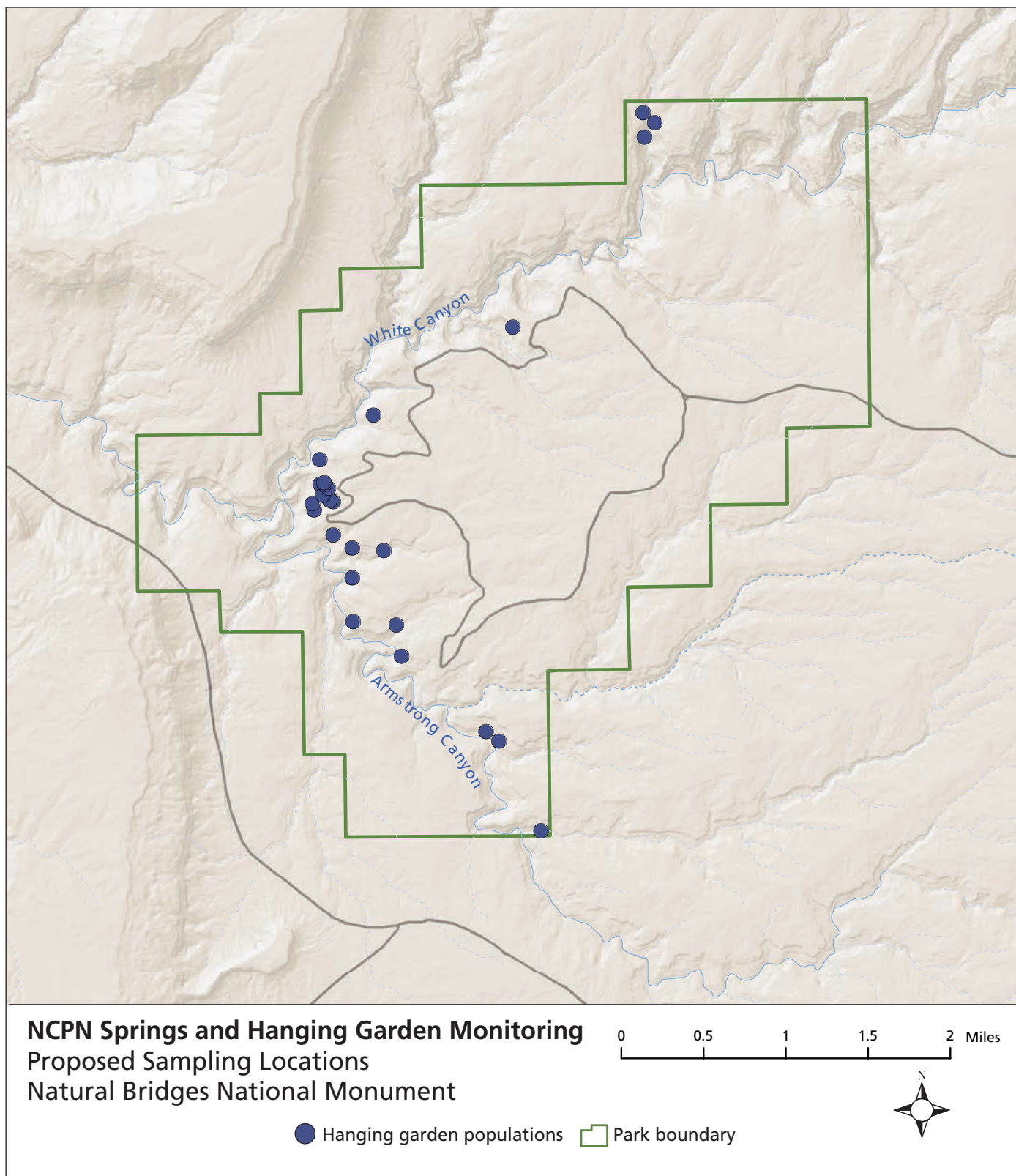


Figure 3-4. Locations of hanging gardens for random sampling at Natural Bridges National Monument.

4 Final Proposed Sampling Design and Revisit Strategy

4.1 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 15 pay periods per year for a technician (GS 5/6/7 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.

4.2 Sentinel sites

Due to the number of high-priority monitoring sites selected, not every site can be sampled every year. A subset of sites will be monitored yearly to detect impacts of unusual or cyclical events that might otherwise be missed, such as El Niño/La Niña climate patterns. The remaining sites will be visited for two years, then rested for two years (Table 4-1).

For sentinel sites with flow monitoring, the 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), the “monthly with no winter” sampling scenario tested above. Site and

Table 4-1. Sentinel monitoring sites with years when flow or vegetation will be sampled and the financial responsibilities of SEUG and NCPN staff.

Site name	Year				Parameter Responsible organization	
	1	2	3	4	Flow	Veg
Arches National Park						
Cordova Canyon South			X	X	NCPN	NCPN
Courthouse Boundary Spring*	X*	X*	X*	X*	SEUG	NCPN
Lost Spring			X	X	NCPN	NCPN
Poison Ivy Spring	X	X	X	X	SEUG	NCPN
Sevenmile Boundary Spring	X	X	X	X	SEUG	NCPN
Sleepy Hollow Spring	X	X	X	X	SEUG	NCPN
Canyonlands National Park (Island in the Sky)						
Alcove Spring			veg			NCPN
Cabin Spring	X	X	X	X	NCPN	NCPN
Holeman Spring	X	X			NCPN	NCPN
Neck Spring		veg				NCPN
Syncline Loop			X	X	NCPN	NCPN
Canyonlands National Park (Needles)						
Big Spring			X	X	NCPN	NCPN
Kirk's Cabin	X	X	X	X	NCPN	NCPN
Little Spring			X	X	NCPN	NCPN
Hovenweep National Monument						
Goodman Point	X	X			NCPN	NCPN
Hackberry House	X	X			NCPN	NCPN
Square Tower Spring	X	X			SEUG	NCPN

In the current staffing plan, NCPN provides funding to SEUG to conduct all of the NCPN-supported flow sampling.

Bolded sites are sampled every year.

*Monitoring at Courthouse Boundary Spring is suspended until a stable monitoring location re-emerges.

vegetation characterization occurs once every four years, coinciding with a flow sampling year, and is allocated approximately 40 hours per year for one technician. Methods are outlined in the NCPN springs monitoring protocol (Weissinger et al. in prep.). 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 of effort per year divided between two technicians. Because of travel requirements, some sites require a full day for sampling, while others can be sampled on the same day (e.g., Cordova Canyon and Lost Spring, Hovenweep sites).

4.3 Random sites

For populations of hanging gardens, the revisit design attempts to balance the need to observe interannual 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. Colluvial slopes in hanging gardens are saturated with water and often have slopes of $\geq 65^\circ$, making them highly susceptible to erosive disturbances (May et al. 1995). As such, trampling impacts are a concern, precluding repeat annual sampling. Randomly sampled hanging gardens are sampled two years in a row and then rested for four years (Table 4-2). Sites will be added in random order until the allocated effort is reached. Sampling methods are detailed in the NCPN springs monitoring protocol (Weissinger et al. in prep.). Ability to detect trend with the available sample size will need to be evaluated after several years of data collection.

Table 4-2. Proposed rotation of randomly sampled hanging gardens.

Site	Year					
	1	2	3	4	5	6
A	X	X				
B		X	X			
C			X	X		
D				X	X	
E					X	X
F, etc.	X	X				

The affordable effort for hanging garden sites with no flow monitoring is approximately 80 hours per year for one technician, including office time for plant identification and data entry. Allocations to various geographic areas are as follows:

- ARCH–Courthouse Wash (29 known sites), 20 hours/year
- ARCH–Upper Salt Wash (20 known sites), 20 hours/year
- ARCH–Freshwater/Delicate Arch (23 known sites), 10 hours/year
- NABR– 19 known sites, 20 hours/year

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