



Mojave Desert Network Inventory and Monitoring Selected Large Springs Protocol

Protocol Narrative

Natural Resource Report NPS/MOJN/NRR—2016/1108



ON THE COVER

A staff gage in MC Spring in Mojave National Preserve.
Photograph by: Geoff Moret

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Standard Operating Procedures

Standard operating procedures (SOPs) are bound in a separate accompanying document.

Logistics and Support

SOP 1: Safety

SOP 2: Staff Training

SOP 3: Spring Locations and Spring-Specific Procedures

SOP 4: Field Mobilization and De-Mobilization

SOP 5: Equipment Disinfection

Sample and Data Collection

SOP 6: Handheld Water Quality Instrument

SOP 7: Spring Discharge Monitoring

SOP 8: Water Sampling, Benthic Macroinvertebrate Sampling and Springsnail Monitoring

SOP 9: Monitoring Water Levels in Wells

SOP 10: Sample Handling

SOP 11: Laboratory Analysis of Benthic Macroinvertebrates

SOP 12: Laboratory Analysis of Water Chemistry

QA/QC

SOP 13: Quality Assurance Project Plan

SOP 14: Cumulative Measurement Bias

Data Management and Analysis

SOP 15: Data Analysis and Reporting

SOP 16: Data Management

SOP 17: Protocol Revision and Review

Executive Summary

The mission of the National Park Service is “to conserve unimpaired the natural and cultural resources and values of the national park system for the enjoyment of this and future generations” (NPS 1999). To uphold this goal, the Director of the NPS approved the Natural Resource Challenge to encourage national parks to focus on the preservation of the nation’s natural heritage through science, natural resource inventories, and expanded resource monitoring (NPS 1999). Through the Challenge, 270 parks in the national park system were organized into 32 inventory and monitoring networks. The Mojave Desert Network (MOJN) includes eight units of the National Park system: Death Valley National Park (DEVA), Great Basin National Park (GRBA), Joshua Tree National Park (JOTR), Lake Mead National Recreation Area (LAKE), Manzanar National Historic Site (MANZ), Mojave National Preserve (MOJA), Grand Canyon-Parashant National Monument (PARA), and Tule Springs Fossil Beds National Monument (TUSK). Collectively, these parks comprise 3.3 million hectares or 9.7 percent of the total land area managed by NPS.

MOJN I&M has identified 20 priority park vital signs- indicators of ecosystem health- which represent a broad suite of ecological phenomena operating across multiple temporal and spatial scales. This protocol addresses three of these vital signs (Surface Water Dynamics, Surface Water Chemistry, and Groundwater Dynamics and Chemistry) in springs that have been selected as high priorities for monitoring. Monitoring of a statistical sample of the spring population (the MOJN I&M Arid Lands Springs protocol, in development) and monitoring of streams and lakes (the MOJN I&M Streams and Lakes protocol, Caudill et al. 2012) are addressed in a separate set of protocols. The data collected for this protocol will be used to monitor:

1. Spring discharge
2. Spring water chemistry and quality
3. Benthic macroinvertebrate and springsnail communities

Discharge will be measured in the field, while spring water chemistry will be measured using in-spring water quality instruments and laboratory analysis of water samples. Benthic macroinvertebrate sampling and springsnail monitoring will be used to directly monitor these important biological communities and simultaneously monitor for biological responses to changes in discharge and water quality.

This protocol details the why, where, how, and when of the monitoring program. As recommended by Oakley et al. (2003), the protocol consists of a narrative and a set of standard operating procedures (SOPs), which detail the steps required to collect, manage, and disseminate the data representing the status and trend of water quality parameters in the network. Collected data, in combination with other vital signs monitoring, will provide a context for the interpretation of status and trends in water resources within the network.

The protocol is intended to be a “living” document that evolves as new information emerges and methodologies are refined. Changes to the protocol are carefully documented in a revision history

log. The first five years of monitoring will address outstanding questions related to site variability, inter-annual variability, and baseline conditions. From there, the focus will shift toward trend analysis, in which ecologically meaningful declines or increases will be detected, and appropriate management strategies can be developed.

Acknowledgments

Funding for this project was provided through the National Park Service Natural Resource Challenge and the Servicewide Inventory and Monitoring Program. This protocol is the result of the work of the MOJN Water Resources Working Group (WRWG) for whose time and effort we are grateful.

WRWG participants over the years have included the authors, Terry Fisk (DEVA), Richard Frieese (DEVA), Kevin Wilson (DEVA), Gretchen Baker (GRBA), Gordon Bell (GRBA), Ben Roberts (GRBA), Bryan Moore (LAKE), Mark Sappington (LAKE) Debra Hughson (MOJA), Boris Poff (MOJA), Gary Karst (WRD), Gary Rosenlieb (WRD), Luke Sabala (JOTR), Don Sada (DRI), Kyle Voyles (PARA), Jennifer Fox (PARA), and Eathan McIntyre (PARA). Kristina Heister and Alice Chung-MacCoubrey's contributions as the previous MOJN I&M Coordinators laid the groundwork for the water-related protocols. Passages and some tables of the introductory text were drawn from their reports on the early efforts of the WRWG. Assistance with data management was provided by Ryan Hodge, Jennifer Burke, and Bob Truitt. This protocol also drew passages from other documents produced by the network, particularly the MOJN I&M Vital Signs Monitoring Plan (Chung-MacCoubrey et al. 2008) and the MOJN I&M Streams and Lakes Protocol (Caudill et al. 2012). We thank former Pacific West I&M Coordinator Penny Latham for her help in processing task agreements to fund the network water quality monitoring and for her assistance in her role as interim MOJN I&M Program Manager in 2010.

Abbreviations

ADWR: Arizona Department of Water Resources
AICc: Corrected Akaike Information Criterion
AMS+: Alternative Measurement Sensitivity Plus
BIC: Bayes Information Criterion
BLM: Bureau of Land Management
BMI: Benthic macroinvertebrates
CA DWR: California Department of Water Resources
DEVA: Death Valley National Park
DM: Data Management Plan
DRI: Desert Research Institute
EMAP: Environmental Monitoring and Assessment Program
EPT: Ephemeroptera, Plecoptera, and Trichoptera
EQulS: Environmental Quality Information System
ET: Evapotranspiration
FGCD: Federal Geographic Data Committee
GRBA: Great Basin National Park
HUC: Hydrologic Unit Code
I&M: Inventory and Monitoring
IAR: Investigator Annual Report
JHA: Job Hazard Analysis
JOTR: Joshua Tree National Park
LAKE: Lake Mead National Recreation Area
MANZ: Manzanar National Historic Site
MDL: Method Detection Limit
MOJA: Mojave National Preserve
MOJN: Mojave Desert Network
MOJN I&M: Mojave Desert Network Inventory and Monitoring Program
MQO: Method Quality Objective
NPS: National Park Service
NPS WRD: National Park Service Water Resources Division
PARA: Parashant National Monument
QAPP: Quality Assurance Project Plan
RL: Reporting Limit
RLFCT: Relict Leopard Frog Conservation Team
RPD: Relative Percent Difference
SOP: Standard Operating Procedure
TUSK: Tule Springs Fossil Beds National Monument
US EPA: United States Environmental Protection Agency
USGS: United States Geological Survey

Abbreviations (continued)

WASO: NPS Washington Office

WRD: Water Resources Division

1. Background, Rationale, and Objectives

In this chapter, we provide background information about the MOJN parks, describe their water resources, and provide an overview of management issues related to their springs. We then provide a rationale for developing a monitoring protocol for a small number of springs in each park. Next, we describe the monitoring questions that motivate the protocol, and demonstrate how the collected data will be used to answer those questions.

1.1. Background

1.1.1. Overview of the Geography of the MOJN Parks

(This section adapted from Chung-MacCoubrey et al. 2008)

The eight park units in Arizona, California, and Nevada (Figure 1) encompass a total of nearly 3.3 million hectares of land (Table 1) within three contiguous semi-arid desert ecosystems (the Great Basin, Mojave, and Sonoran deserts). Across these deserts there is a gradient of increasing temperature and decreasing elevation from north to south. GRBA is located northward within a high-elevation cold desert environment, whereas the other parks are located southward, in a hot desert environment. PARA contains hot desert in its western portion and cold desert in its higher elevation, Colorado Plateau portion. Significant topographic relief and elevation gradients generate gradients in climate and local temperature regimes through the interaction of air density, solar radiation, precipitation, and slope. In turn, these climate gradients strongly influence the availability of surface water and the distribution of plant and animal communities.

As a result of the rain shadow created by the Sierra Nevada and the Transverse Ranges, water is scarce, and a dry desert environment prevails across the MOJN area. From the Pacific Ocean, the moist air masses travel eastward, rising, cooling, and dropping the bulk of their moisture load as rain or snow once they meet mountain ranges. Precipitation increases with increasing elevation and from west to east across the region, especially during the summer and fall monsoon seasons. During the monsoons, localized convective storms or tropical depressions develop, moving northward from the Gulf of California and South Pacific Ocean. The rain and snow that precipitates on the mountains ultimately enters watersheds, some of which drain into desert basins. Runoff in the mountains creates surface flows that can transport large sediment loads, which are deposited downstream in the alluvial valleys and playas. The more northerly location and higher elevation at GRBA result in relatively high precipitation and a higher density of surface water expressions than for the southern desert parks, which lack natural lakes or permanent headwater streams.

The geography of the six parks monitored in this protocol is summarized briefly below; an overview of their aquatic resources follows in the next section. MANZ and TUSK do not contain springs, and are not discussed further.

Death Valley National Park was founded as a national monument in 1933 and became a national park in 1994. DEVA occupies 1.37 million ha and is the largest NPS unit in the contiguous United States. The park lies near the southern boundary of the Great Basin Desert and the northern boundary of the

Mojave Desert. Two mountain ranges flank DEVA to the west and east, producing dramatic topographic relief. DEVA includes the lowest point in North America (Badwater, 86 m below sea level), receives the least precipitation in the United States, and claims the world's highest recorded temperature (Furnace Creek, 57 C). Because hot desert species are found at lower elevations and cold desert species are found at higher elevations, DEVA supports diverse assemblages of plant and animal life. Various habitats such as springs, drainages, playas, sand dunes, and subterranean pools are home to a plethora of endemic species that have adapted to DEVA's unique and harsh environment (e.g., Devils Hole pupfish, [*Cyprinodon diabolis*]).

Great Basin National Park was established in 1986 after being originally founded as Lehman Caves National Monument in 1922. GRBA occupies 31,161 ha and lies wholly within the Great Basin Desert region and the South Snake Range in east-central Nevada. GRBA is the most mountainous MOJN park with nearly 10% of its land above 3,000 meters, reaching the highest point in the Snake Range at Wheeler Peak (3,982 m). Due to the high elevation of the Snake Range, this range receives more moisture than many adjacent mountain ranges. Average annual precipitation in surrounding valleys is approximately 15 cm. Within the park, average annual precipitation at Lehman Cave is approximately 30 cm but may range up to 63+ cm at high elevations (e.g., Wheeler Peak). GRBA is known for its glacial formations and karst geology producing at least 45 natural caverns harboring a variety of biological and geological cave resources. The combination of moisture gradients, geologic history, and the isolation of higher alpine and subalpine areas in GRBA has produced several endemic plant and animal species.

Joshua Tree National Park was founded in 1936 and occupies 319,702 ha. JOTR is the southern-most park in MOJN and lies at the transition between the Mojave and Sonoran deserts and within the west-east oriented Southern California Mountains. In this compressed transition zone between three ecosystems, the park supports a unique diversity of desert flora and fauna. Five of North America's 158 desert fan palm oases occur in JOTR, where fault lines that run through igneous and metamorphic rocks force water to the surface. A diverse and unique assemblage of species, especially reptiles, is dependent on these water sources. Currently, species that are actively managed within the park include the federally threatened desert tortoise (*Gopherus agassizii*), desert bighorn sheep (*Ovis canadensis nelsoni*), Mojave fringe-toed lizard (*Uma scoparia*), and sensitive bat species.

Lake Mead National Recreation Area was established in 1947 after being originally founded as Boulder Dam Recreation Area through a memorandum of agreement with the Bureau of Reclamation (BOR) in 1936. LAKE occupies almost 607,000 ha and is the fourth-largest NPS unit in the contiguous United States. LAKE lies along the northeast boundary of the Mojave Desert and includes a portion of the high Colorado Plateau ecosystem on its eastern edge. The recreation area encompasses 229 km of the Colorado River and is centered around two large reservoirs, Lake Mead and Lake Mojave. The Colorado River reservoirs and associated lake shoreline, a reach of the Las Vegas Wash (a natural intermittent stream used to discharge the region's treated wastewater to Lake Mead), and the recreation area's desert springs preserve one of the Southwest's most threatened habitats – the desert riparian community. As a result, there are significant populations of many

species of special concern in the park (NPS 2002). LAKE is also a popular inland water recreation area and the primary source of drinking water for southern Nevada.

Mojave National Preserve was founded in 1994 and occupies almost 647,000 ha, making it the third-largest NPS unit in the contiguous United States. MOJA lies in the south-central Mojave Desert and has strong floristic influences from the Sonoran Desert along its southern boundary. The preserve encompasses a vast expanse of hot desert set among a landscape of mountain ranges, high elevation sand dunes, great mesas, and extinct volcanoes (NPS 2000). Similar to DEVA, the dunes in MOJA constitute unique environments with specially adapted endemic plants and animals. MOJA offers the densest population of Joshua trees (*Yucca brevifolia*) in the world. In addition, approximately half of the lands within the preserve have been designated Critical Habitat for the desert tortoise, *Gopherus agassizii*, a species federally listed as threatened (NPS 2000).

Grand Canyon-Parashant National Monument was founded in 2000. PARA occupies 424,240 ha, and this land is jointly managed by the NPS and Bureau of Land Management (BLM). The monument lies on the northeast edge of the Mojave Desert at the boundary between floristic provinces, with low elevations represented by classic, hot desert Mojave Desert scrub, and upper elevations represented by cold desert Colorado Plateau vegetation. The intersection of these biomes is a distinctive feature that has given rise to elevated biological diversity within PARA (Stevens 2001). The most prominent topographic feature within the monument is the Shivwits Plateau, which is physiographically and stratigraphically typical of the Grand Canyon region.

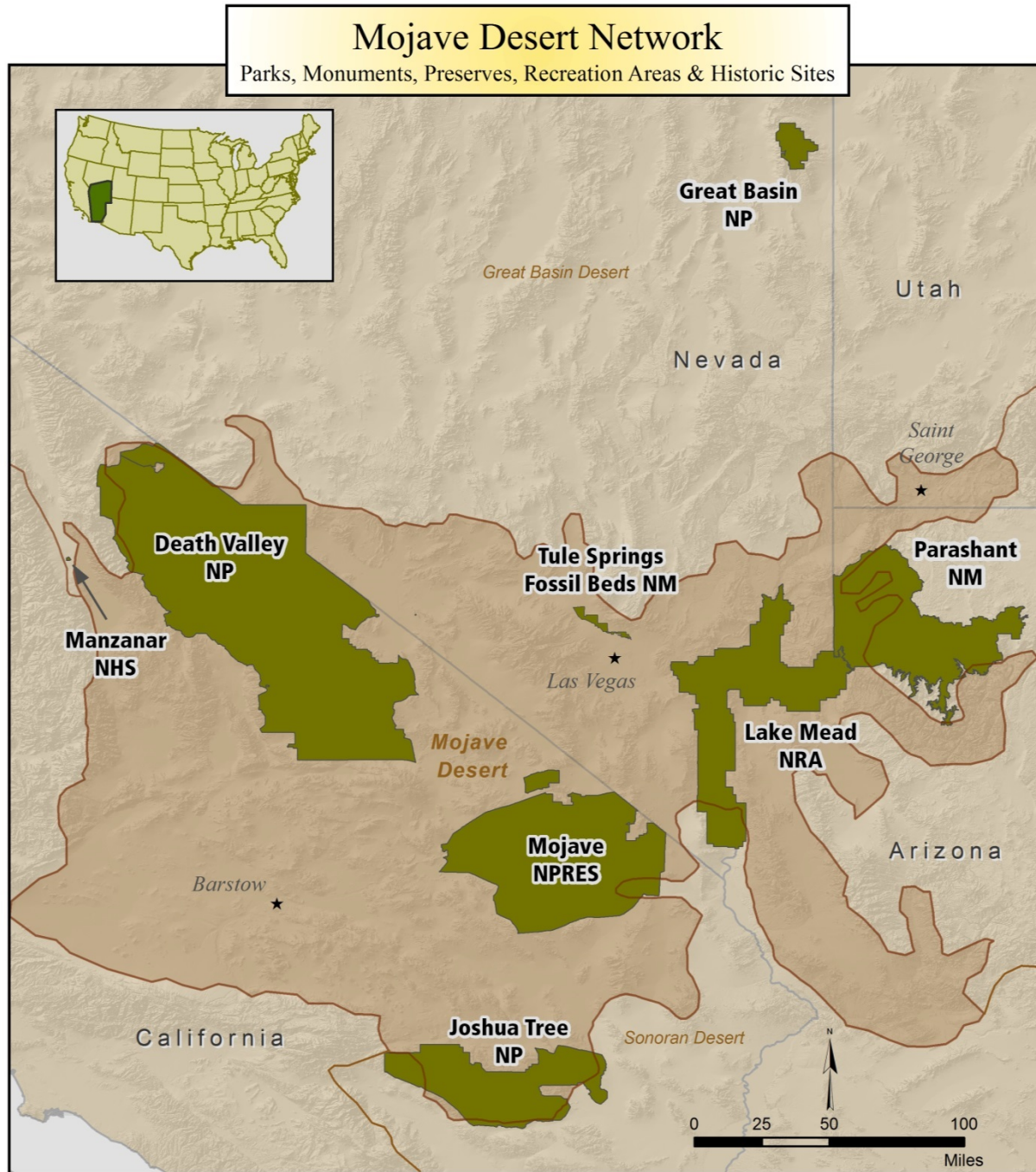


Figure 1. Parks of the Mojave Desert I&M Network.

1.1.2. Aquatic Resources

Freshwater monitoring in MOJN parks is part of a monitoring program designed using an integrated, hierarchical set of ecological models to identify key drivers and stressors and select appropriate vital signs (Chung-MacCoubrey et al. 2008). In this framework, streams, lakes, springs, and groundwater are components of the wet systems. Wet systems themselves are a component nested in an overall framework model composed of wet systems, dry systems, the atmospheric system, and the human social system (Chung-MacCoubrey et al. 2008).

Permanent streams and lakes are fed by direct precipitation, snowmelt, and groundwater discharge. As shown in Table 1, there are a relatively small number of streams and lakes in the network due to the aridity of the Mojave Desert. The MOJN I&M Streams and Lakes Protocol (Caudill et al. 2012) monitors permanent streams and lakes. The large rivers and reservoirs in LAKE are intensely monitored by other programs and agencies (Turner et al. 2010), so the MOJN I&M Streams and Lakes protocol is focused on the aquatic resources of GRBA. The protocol can be downloaded from: http://www1.nrintra.nps.gov/im/units/mojn/vitalsigns/streams_lakes_main_intranet.cfm.

Table 1. Surface water resources of the MOJN parks.

Park	Area (ha)	Elevation Range (m)	Permanent Rivers	Permanent Streams	Ponds & Lakes	Reservoirs	Springs
Death Valley NP (DEVA)	1,374,420	-86–3,368	0	4 ^a	0	0	629
Great Basin NP (GRBA)	31,194	1,615–3,981	0	10	6	0	426
Joshua Tree NP (JOTR)	321,327	0–1,772	0	0	0	4 small (100s of m long)	109
Lake Mead NRA (LAKE)	521,346 ^b	152–1,719	3	1	0	2 very large (10s of km long)	89
Manzanar NHS (MANZ)	329	1,158	0	0	0	0	0
Mojave Nat'l. Pres (MOJA)	619,923	274–2,438	0	0	0	0	238
Grand Canyon-Parashant NM (PARA)	424,242 ^c	366–2,447	0	1 ^a	0	0	206
Tule Springs Fossil Beds NM (TUSK)	9,158	645–1,008	0	0	0	0	0

^a Stretches of Salt Creek, Furnace Creek, Cottonwood Creek, and Darwin Creek (DEVA) and Pakoorn Wash (PARA) are perennial due to spring flow.

^b Excludes 84,358 hectares of NPS-owned land currently within LAKE boundary that is now part of PARA; Total park acreage for LAKE including NPS-owned land within PARA is 605,704 hectares.

^c Total size of PARA includes 84,358 hectares of NPS-owned land, 327,288 hectares of BLM-managed lands, and 12,595 hectares of non-federal lands.

At the five large southern desert parks (DEVA, JOTR, LAKE, MOJA, and PARA), springs often represent the only surface water over large areas. As a result, springs are extremely important as habitat for fish (e.g. Henkanaththege et al. 2008), aquatic invertebrates (e.g. Whitman and Sites 2008, Sada 2005), and riparian plant species (e.g. Lacznia et al. 2006) as well as water sources for terrestrial wildlife (e.g. Longshore et al. 2009).

1.1.3. Current Monitoring of Springs and Wells in MOJN Parks

The selected large springs are considered to be of great importance by MOJN park managers, and some of MOJN parks have existing monitoring efforts at the selected large springs:

- DEVA currently monitors discharge and water quality at all five of its selected large springs as well as a network of monitoring wells. This monitoring is conducted in close coordination with and with the support of WRD.
- The USGS monitors discharge at Rogers Spring. Funding for this effort is currently provided by LAKE, and was previously provided by WRD.
- Interagency teams monitor the Mohave tui chub at MC Spring in MOJA and the relict leopard frog at Blue Point Spring and Rogers Spring in LAKE and Tassi Spring in PARA.
- Park staff monitor the use of springs by wildlife in all parks.

This protocol is intended to complement these efforts rather than duplicating or replacing them.

1.2. Rationale for Monitoring Selected Large Springs

1.2.1. Rationale for Monitoring Aquatic Resources in MOJN Parks

The National Park Service was established by Congress with the passage of the National Park Service Organic Act in 1916. The Organic Act directs the National Park Service to manage federal areas known as national parks, monuments, and reservations “which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.” In 1999, the NPS approved the Natural Resource Challenge (NPS 1999), which stated, “The protection of National Park waters, watersheds, and aquatic life is fundamental to maintaining the integrity of natural resources and the quality of the visitor experience in the parks. A consistent approach to identifying and measuring progress toward meeting water quality standards is essential. Protective standards, scientific monitoring, and a program to ensure the protection of water quality, natural flows, and the health of aquatic systems are required to measure and protect this critical environmental component.” However, the past availability of water quality data for the parks has been inconsistent due to the variety of agency and state efforts and protocols. The NPS goal is to rely on its own uniform monitoring data to protect this vital resource.

To that end, the intent of the NPS Inventory and Monitoring Program (I&M) is to track a subset of “vital signs”, including those for water resources (Chung-MacCoubrey et al. 2008). Vital signs are a subset of physical, chemical, and biological elements and processes of park ecosystems that are

selected to represent the overall health or condition of park resources, the known or hypothesized effects of stressors, or elements that have important human values or resource significance.

1.2.2. Rationale for a Separate Selected Large Springs Protocol

The selection of vital signs for monitoring in MOJN parks was a multiyear, multiagency collaborative process that identified the monitoring of surface and ground water as high priorities (Chung-MacCoubrey et al. 2008). Surface water quantity and surface water chemistry ranked 4th and 14th, respectively, while groundwater dynamics and chemistry were ranked 5th.

MOJN park natural resource managers are very concerned with monitoring the integrity of all aquatic resources. However, the original Groundwater and Springs Protocol Development Summary (Appendix I of Chung-MacCoubrey et al. 2008) makes it clear that the parks' priority is for certain springs to be monitored:

“While a probabilistic sample is desirable, monitoring will focus on a set of index or sentinel sites due to specific management priorities, limited resources, and the difficulty of defining a meaningful sampling frame for the ecologically heterogeneous, large, and high discharge springs in the network....Future monitoring of the numerous local and perched aquifer-springs using a probabilistic sampling design is feasible using the methods and SOPs that will be described in this protocol should resources and funding become available in the future.”

MOJN I&M has decided to meet the goals laid out in the original Protocol Development Summary with two protocols: the Arid Lands Springs protocol and the Selected Large Springs protocol. Two protocols are needed because they have different objectives and different monitoring parameters.

The MOJN I&M Arid Lands Springs protocol will attempt to monitor the more than 1,000 springs by visiting a statistically-selected sample of springs in DEVA, JOTR, LAKE, MOJA, and PARA. The protocol will consist of annual visits to each spring to monitor water quality, water quantity, riparian vegetation, and site disturbance. Sensors will be deployed in each spring to monitor the timing of the wet and dry periods. The Arid Lands Springs protocol has yet to be developed.

While the Arid Lands Springs protocol will provide information about the overall springs population, there are individual springs within each park that have been identified as high-priority targets for intensive monitoring. These springs were selected by park managers for a variety of reasons, but their common traits are that the springs are generally among the highest discharge springs in each park and they are generally among the most reliable sources of water in each park. For this reason, the protocol for monitoring these springs has been named the MOJN I&M Selected Large Springs protocol, although the monitored springs are not necessarily the largest in the network. Each spring will be visited quarterly, and the monitored parameters include discharge, water quality, water chemistry, benthic macroinvertebrate communities, and springsnail populations. The rationale for the selection of each spring is described in section 1.5.

1.2.3. Rationale for Monitoring Water Levels in Selected Wells

As discussed in Section 1.1.3, one of the special issues facing the springs of the MOJN parks is the threat of reduced discharge due to groundwater withdrawals. However, Bredehoeft and Durbin

(2009) demonstrated that the effect of up-gradient groundwater withdrawals on springflows in large regional aquifers may take decades to detect, and that springflows may not recover for centuries, even if pumping is stopped entirely. In general, the wells in the parks are not far enough up-gradient of the springs to detect these changes before the springs are impacted. However, monitoring well data will help determine whether changes in springflow are due to changes in water levels in the aquifer (due to pumping or other factors) or changes in the rate of ET due to changes in vegetation. In addition, spring discharge records can be compared to water level records from wells completed in a particular aquifer to provide evidence that the spring is fed by that aquifer. Monitoring water levels in the aquifers that are the sources of the selected large springs is a high priority for park managers, and was envisioned as a component of the proposed monitoring in the original Groundwater and Springs Protocol Development Summary (Appendix I of Chung-MacCoubrey et al. 2008). Therefore, we have included it in the Selected Large Springs protocol.

1.3. Springs Selection

The springs monitored under the Selected Large Spring protocol were selected in consultation with park staff in order to address park management needs. Because data from different springs will not be combined to make inferences regarding a larger population, the parks were free to prioritize springs according to their own criteria. Most of the selected springs:

- are among the highest discharge springs in their parks,
- are important habitats for amphibians, fish, and/or endemic invertebrates, and
- are important sources of water for wildlife.

The final list of springs was chosen based on park prioritization and a consideration of the staff available for the monitoring effort.

1.4 Selected Large Springs in DEVA

Five springs have been selected for monitoring in DEVA (Table 2): Texas Springs, Travertine Springs, Nevares Springs, Mound Spring, and Saratoga Spring. The locations of these springs are shown in Figure 2.

Table 2. Discharge and water quality data for selected large springs in DEVA. Data from Sada and Jacobs (2008a), (Travertine and Nevares), DEVA staff (Mound), and MOJN staff (Texas and Saratoga).

Spring	Discharge (m ³ /day)	Temperature (°C)	Diss. Oxygen (mg/L)	pH (Standard Units)	Specific Conductance (µS/cm)
Mound Spring	376	37.5	3.24	7.14	1,112
Texas Springs	1077*	31.5	7.61	8.02	945
Travertine Springs	4037*	33.9	4.8	7.55	1,222
Nevares Springs	881*	37.7	0.31	7.5	1,210
Saratoga Spring	425**	28.6	4.02	7.63	4,590

* Data from NPS WRD (Gable and Stevenson 2013a and 2013b, Chafey et al. 2015).

**Data from Miller (1977)

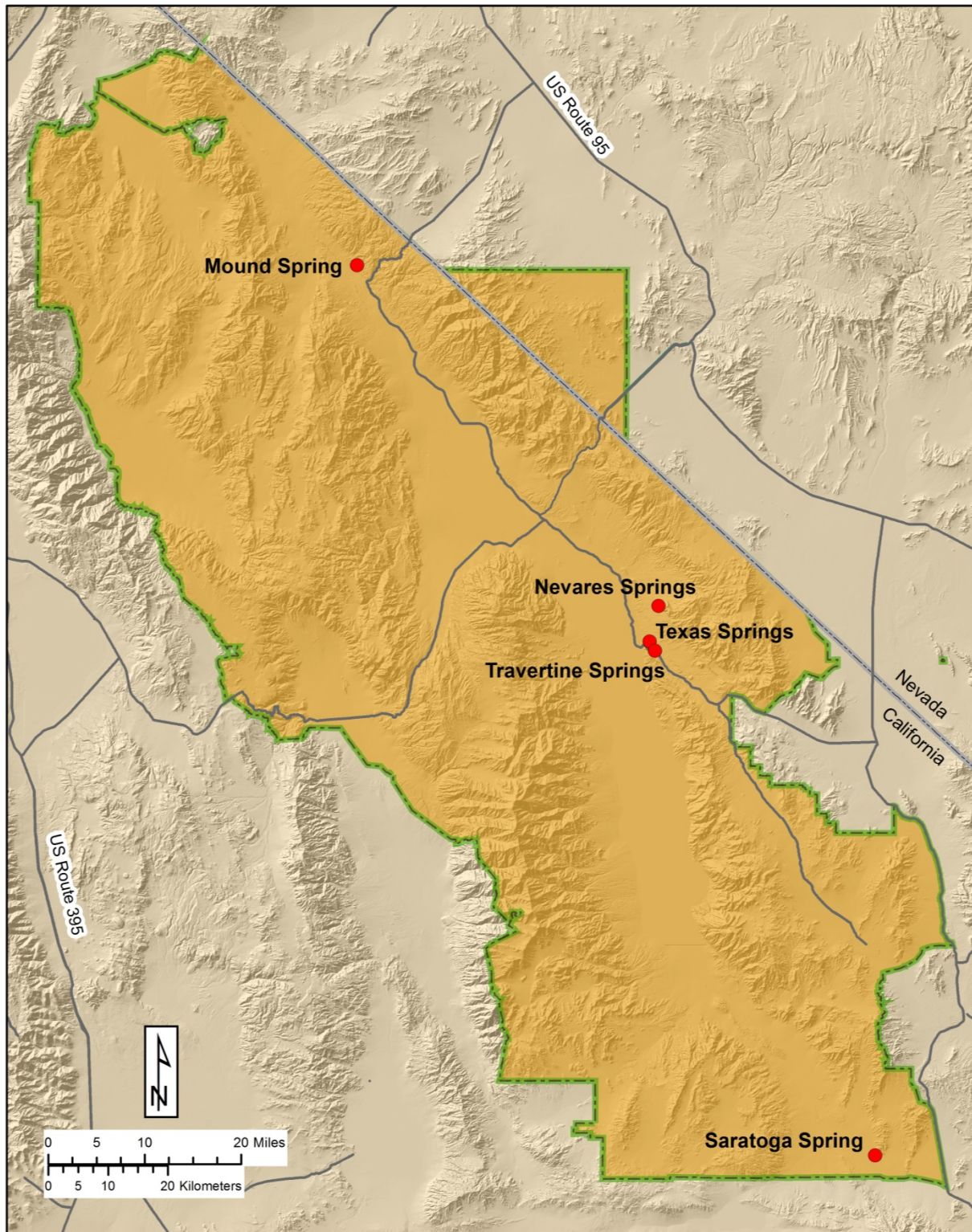


Figure 2. Map of springs selected for monitoring in DEVA.

1.4.1 Texas Springs

Location and Description: Texas Springs (Figure 3) is located in the Furnace Creek area of DEVA. Currently, the discharge from the historic collection system is released to the ground surface, where it forms a small pool. This water flows into a spring brook that runs for roughly 200 meters before flowing into a narrow, deeply-incised ravine up to 5 meters deep (Figure 3). Annual mean discharge measured at a Parshall flume at Texas Spring that was in operation between 1989 and 2008 was 1077 cubic meters per day (Gable and Stevenson, 2013a). Lacznia et al. (2006) estimate that the spring supports 11 acres (4.5 hectares) of riparian vegetation, resulting in 24 acre-feet per year (81 cubic meters per day) of ET.

Site History: Discharge from Texas Spring's discharge was diverted sometime before 1941 to provide water to the U.S. Borax and Chemical Corporation. Subsequently, Texas Spring provided water to the Texas Springs Campground, and to a 2 million gallon storage tank that served as a potable water supply for the Furnace Creek area. The collection galleries, french drains and tunnel used to collect spring discharge left the spring ecosystem highly disturbed. The diversion is estimated to have reduced the historic springbrook length by 85% (Threlhoff and Koenig 1999). While no records are available, the morphology of the ravine suggests that it was formed by the release of water from the collection system onto the hill slope.

Fauna: The spring supports the Amargosa Naucorid (*Pelocoris shoshone amargosus*) and a population of springsnails (*Tryonia robusta*). A preliminary list of BMI taxa present in the spring can be found in Moret et al. (2014a).



Figure 3. Riparian area and incised ravine below Texas Springs flume box in DEVA in March 2008. Photo by C. Caudill.

1.4.2. Travertine Springs

Location and Description: Travertine Springs is located in the Furnace Creek area of DEVA, east of Highway 190. Travertine Springs includes at least 10 spring outlets scattered over an area of about 35 hectares (Sada and Cooper, 2012). Annual mean discharge measured at a Parshall flume at Travertine Springs was 4037 cubic meters per day for the period from 1989 to 2008 (Gable and Stevenson, 2013b). Some flow bypassed the flume during this period. There are currently two outlets, Travertine #1 and Travertine #2, that flow in well-defined springbrooks. Travertine No. 1 flows from a pipe (part of a former collection system) on top of a spring mound. The spring flows through a narrow channel down the flank of the spring mound into a wash below. Once in the wash, the spring flows for several hundred meters until it is diverted into a drain on the shoulder of Furnace Creek Road. Travertine No. 2 flows from a pipe near the head of a wash several hundred meters to the west of Travertine No. 1. Currently, the springbrook extends for several hundred meters. Laczniaak and others (2006) estimates that the spring supports 21 acres (8.5 hectares) of riparian vegetation, resulting in 45 acre-feet per year (152 cubic meters per day) of ET, although the spring's riparian vegetation has changed greatly since that data was collected.

Site History: Until recently, the NPS diverted much of Travertine Springs discharge for use within the park, including diversions to Xanterra Parks and Resorts and the Timbisha Shoshone tribe. As of 2014, rehabilitation is ongoing. Mature palms at the spring were consumed by fire in August 2010, and the riparian corridor has been restored with native vegetation (Figure 4).

Fauna: The spring supports populations of the springsnail *Ipnotobius robusta* (Hershler and Liu 2008), the Nevares Springs Naucorid Bug (*Ambrysus funebris*; Sada and Cooper 2012), and the Badwater Snail (*Assiminea infima*; Sada 2001).



Figure 4. Travertine Springs in March 2015. Photo by C. Matesich.

1.4.3. Nevares Springs

Location and Description: Nevares Springs is located in the Cow Creek residential area of DEVA. . Annual mean discharge measured at a Parshall flume at Nevares Springs was 881 cubic meters per day for the period 1989 – 2011 (Chafey and others, 2015). The spring emerges in a marshy area on top of a spring mound (Figure 5), then flows into a wash where it forms a springbrook several hundred meters in length. Lacznia et al. (2006) estimate that the spring supports 29 acres (11.7 hectares) of riparian vegetation, resulting in 61 acre-feet per year (206 cubic meters per day) of ET.

Site History: Until recently, much of the spring’s discharge was diverted for park use. In 2014, NPS began evaluating whether a well at the top of the spring mound can be used as the water supply source in place of discharge from the spring.

Fauna: The springbrook supports populations of the springsnail *Ipnotobius robusta* (Hershler and Liu 2008), the Badwater Snail (*Assiminea infima*; Sada 2001), and the endemic Nevares Springss Naucorid Bug (*Ambrysus funebris*; Whiteman and Sites 2008).



Figure 5. Nevares spring in DEVA in March 2014. Photo by M. Levandowski.

1.4.4. Mound Spring

Location and Description: Mound Spring is located in the Grapevine Springs area in the Grapevine Mountains in the northeastern portion of DEVA. Lacznia et al. (2006) used satellite imagery and weather station data to estimate the total ET discharge of the Grapevine Springs area at 405 acre-feet per year (1368 cubic meters per day). While most of the discharge occurs as ET, there are several discrete spring outlets in the complex. The discrete springs and diffuse discharge areas support approximately 190 acres (77 hectares) of riparian vegetation (Lacznia et al. 2006).

Site History: Historically, some of the surface water discharge from the Grapevine Springs area was diverted to Scotty's Ranch. In 2008, MOJN I&M and DEVA personnel installed a flume at Mound Spring, one of the highest elevation springs in the area (Figure 6). This outlet was chosen as an index site for the Grapevine Springs area because of its relatively high discharge and the suitability of its source for flume installation.

Fauna: The area supports populations of two endemic springsnails of the *Tryonia* genus (*T. margae* and *T. rowlandsi*; Hershler et al. 1999) and one springsnail of the *Pyrgulopsis* genus that is more widely distributed (*P. micrococcus*; Hershler and Liu 2008).



Figure 6. Mound Spring in DEVA, April 2010. Photo by R. Friese.

1.4.5. Saratoga Spring

Location and Description: Saratoga Spring is located near the southern end of DEVA (Figure 1). Discharge from Saratoga Springs historically ranged from 414 to 436 cubic meters per day (Miller, 1977), and it supports approximately 7 hectares of wetlands vegetation (primarily reeds and bulrushes) and open water. At the southern end of the spring, water flows from a historic spring box to a source pool that is approximately 10 meters in diameter. From the source pool, water flows north along a low-banked channel through the reeds to a series of artificial downstream ponds (Figure 7), the largest of which is approximately 60 meters by 200 meters.

Site History: Throughout its history, the spring has been used as a watering stop for mule teams, the water supply for nearby mines, the source for a water bottling operation, and a tourist spa (Latschar 1981), so the area has been highly disturbed. Historical water chemistry data from 1917 onwards (Table 3) indicate that water quality has been stable over that time period.

Fauna: Saratoga Springs supports the endemic Saratoga Springs pupfish (*Cyprinodon nevadensis nevadensis*), the endemic Saratoga Springs belostoman bug (*Belostoma saratogae*), and three springsnail species: *Pyrgulopsis amargosae*, an unidentified species of the genus *Pyrgulopsis*, and *Tryonia variegeta* (Hershler and Liu 2008; Hershler et al. 1999). A preliminary list of BMI taxa present in the spring can be found in Moret et al. (2014b).



Figure 7. Saratoga Spring at DEVA, March 2012. Photo by G. Moret.

Table 3. Historical water quality data for Saratoga Spring in DEVA.

Sample Date	Sp. Cond. µS/cm	pH pH units	Temp °C	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	SO ₄ mg/l	HCO ₃ mg/l
09/08/1917 ¹	--	--	28.3	31	36	994 ⁵	--	1,040	410
03/31/1955 ²	4,680	7.8	--	33	36	989	40.0	1,030	428
12/22/1955 ¹	4,640	8.1	--	33	34	970	30.0	1,040	420
09/02/1963 ¹	--	8.0	--	35	33	955	32.0	1,050	406
12/31/1964 ¹	4,680	7.9	28.3	34	35	990	32.0	1,040	416
04/08/1967 ²	4,720	8.0	29.0	34	21	1,000	40.0	1,040	435
05/04/1992 ³	4,625	7.7	28.0	31.8	34.7	977	34.9	1,020	427
03/28/1998 ⁴	4,700	7.9	28.5	--	--	--	--	--	--

¹Reported by Kunkel (1966)²Reported by Miller (1977)³Reported by Hershey et al. (2010)⁴Reported by Sada and Pohlmann (2007)⁵Calculated total of Na and K

1.5. Selected Large Springs in GRBA

Three springs have been selected for monitoring in GRBA (Table 4): Boiler Spring, Marmot Spring, and Strawberry Source Spring. The locations of these springs are shown in Figure 8.

Table 4. Discharge and water quality data for selected large springs in GRBA. Data collected by GRBA personnel in 2003 and 2004. The ranges of values given for the discharges are the uncertainties in the ocular estimates.

Spring	Discharge (m ³ /day)	Temperature (°C)	Diss. Oxygen (mg/L)	pH (Standard Units)	Specific Conductance (µS/cm)
Boiler Spring	245 to 2450 (estimated)	7.3	6.86	7.74	333.5
Marmot Spring	24.5 to 245 (estimated)	7.7	5.25	6.57	37.5
Strawberry Source Spring	24.5 to 245 (estimated)	5.6	5.86	6.40	50

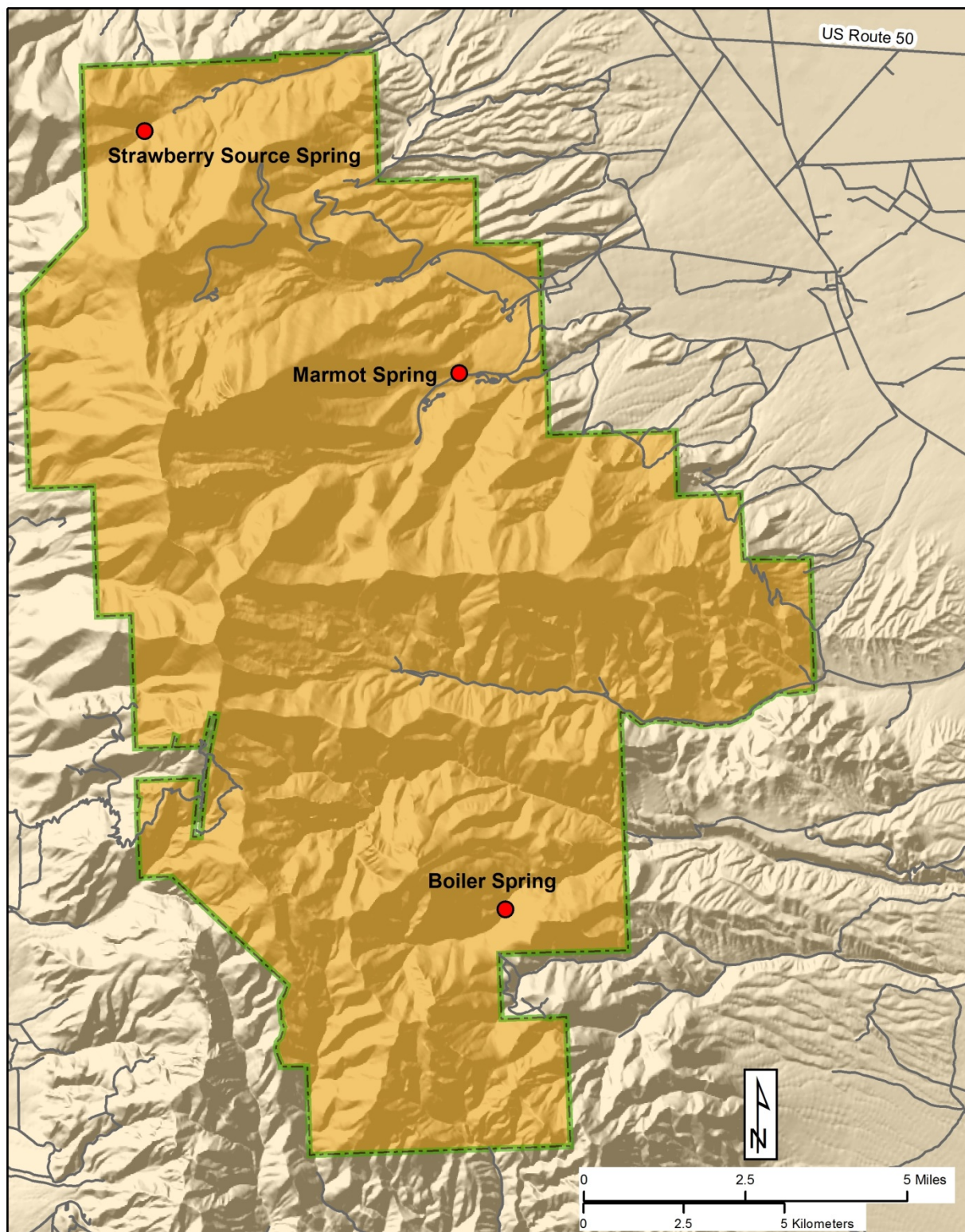


Figure 8. Map of springs selected for monitoring in GRBA.

1.5.1. Marmot Spring

Location and Description: Marmot Spring is a small spring in the Baker Creek drainage that emerges in a shallow swale before being channeled into a culvert beneath Baker Creek Road (Figure 9). The spring supports a small wet meadow crossed by several small channels.

Site History: There is no evidence of human manipulation of the spring system other than the construction of Baker Creek Road.

Fauna: A site survey conducted by GRBA staff in 2004 noted the presence of clams. Clams found in Nevada generally belong to the order Veneroida, family Sphaeriidae (Wildlife Action Plan Team 2013).



Figure 9. Marmot Spring at GRBA, May 2014.

1.5.2. Boiler Spring

Location and Description: The south fork of Big Wash has two perennial stream segments, and Boiler Spring (Figure 10) is the source of the upper segment, which is approximately 2 kilometers long. The riparian corridor in vicinity of the spring-head is dominated by dogwoods.

Site History: There is no evidence of human manipulation of the spring system.

Fauna: The upper stream segment supports a population of native Bonneville cutthroat trout (*Onchorynchus clarki utah*).



Figure 10. Boiler Spring at GRBA, July 2004.

1.5.3. Strawberry Source Spring

Location and Description: Strawberry Source Spring is located at the head of Strawberry Creek. The spring emerges from a slope of mossy boulders, and trickles through rocks for approximately 100 meters before entering a well-defined channel (Figure 11).

Site History: There is no evidence of human manipulation of the spring system.

Fauna: There is no evidence that the spring is an important water source for wildlife. The spring is the headwater for Strawberry Creek, which has a population of Bonneville cutthroat trout (*Onchorynchus clarki utah*).



Figure 11. Strawberry Source Spring at GRBA in May 2014. The spring flow between and beneath the mossy rocks.

1.6. Selected Large Springs in JOTR

Two springs have been selected for monitoring in JOTR (Table 5): Smith Water Canyon Springs and Fortynine Palms Oasis. The locations of these springs are shown in Figure 12.

Table 5. Discharge and water quality data from selected large springs in JOTR. Data from Sada and Jacobs 2008c.

Spring	Discharge (m ³ /day)	Temperature (°C)	Diss. Oxygen (mg/L)	pH (Standard Units)	Specific Conductance (µS/cm)
Smith Water Canyon Springs	115	7.5	7.49	7.8	525
Fortynine Palms Oasis	not measured	12.9	3.61	7.7	406

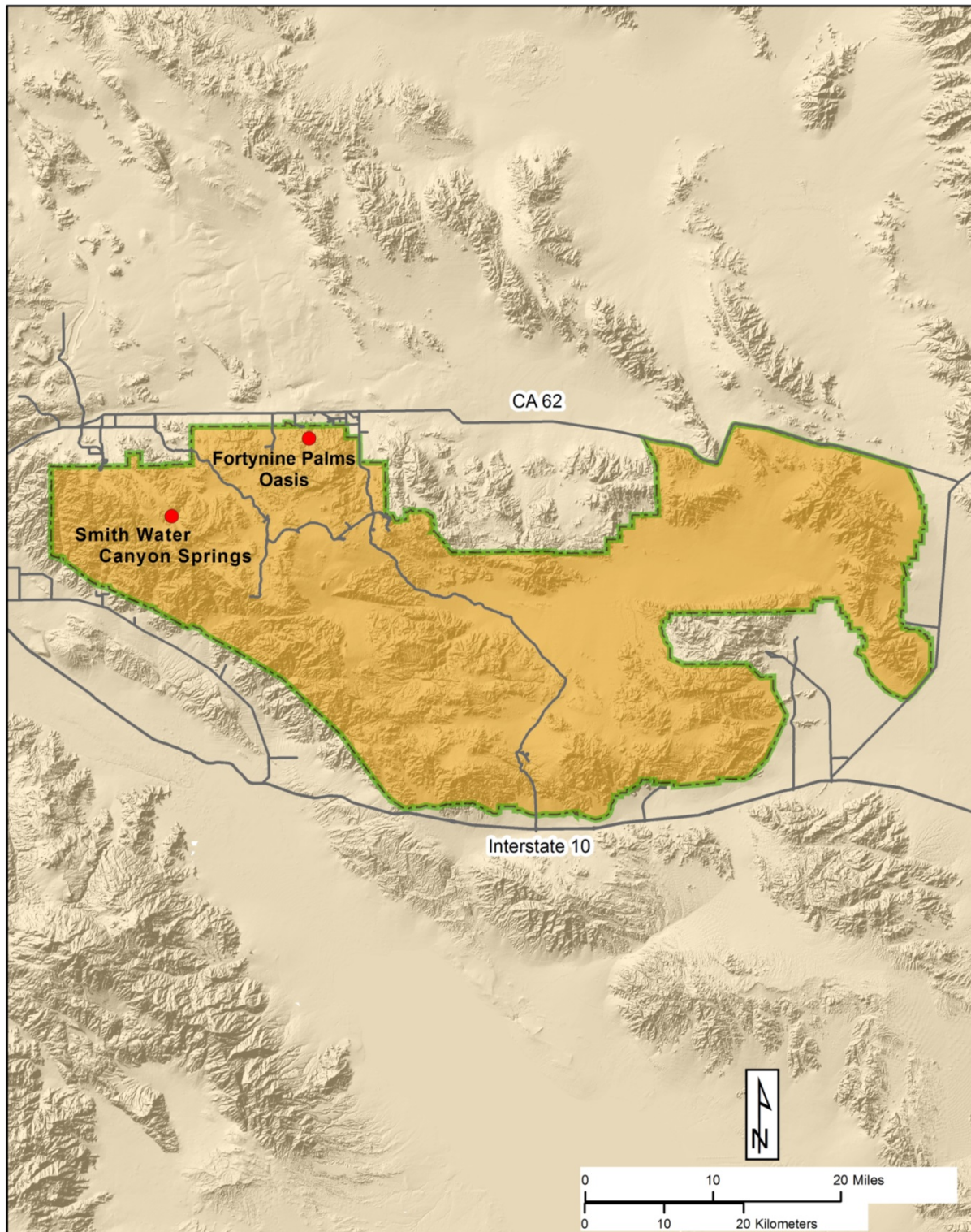


Figure 12. Map of springs selected for monitoring in JOTR.

1.6.1. Smith Water Canyon Springs

Location and Description: Smith Water Canyon Springs is located in Smith Water Canyon, a steep, narrow canyon that descends approximately 1500 feet (457 meters) in elevation from Covington Wash to Quail Wash. The spring emerges from boulders at the base of an ephemeral waterfall, and flows through several natural bedrock depressions (Figure 13).

Site History: There is no evidence of human manipulation of the spring system.

Fauna: Smith Water Canyon is an important water source for desert bighorn sheep (*Ovis canadensis nelsoni*). Mountain lions (*Puma concolor*) have also been observed in the canyon.



Figure 13. Smith Water Canyon Springs, February 2006. Photo from MOJN I&M springs inventory (Sada and Jacobs 2008c).

1.6.2. Fortynine Palms Oasis

Location and Description: Fortynine Palms Oasis is a fan-palm oasis located at the confluence of two washes near the park's northern boundary. The oasis consists of approximately 1 hectare of dense riparian vegetation, principally fan palms and willows (Figure 14). Surface water is present year round in pools below the palms.

Site History: Although the oasis was used as a water source by European Americans, any diversion structures they may have installed have been washed out. The oasis is scoured by major storms every few years. The USGS monitored discharge in the wash below the oasis from 1963 to 1971, and found that, while wash was dry for all but a few days of the year, more than 100 acre-feet (123,300 cubic meters) of water could pass through it in a single storm event (Nishikawa et al. 2004). The USGS attempted to monitor water levels in the oasis pools in 2005 and 2006, and had their equipment destroyed by a storm (Schroeder et al. 2015.). Each time the oasis is scoured, the positions and depths of the pools can change. The frequent changes in the pools present a challenge for long-term monitoring.

Fauna: The oasis is a major water source for desert bighorn sheep (*Ovis canadensis nelsoni*) in the park (e.g., Douglas 1976, Longshore et al. 2009), and is the destination for a popular day hike. Red-spotted toads (*Bufo punctatus*) and California treefrogs (*Pseudacris cadaverina*) have been observed in the oasis (Schroeder et al. 2015).



Figure 14. Fortynine Palms Oasis in JOTR in July 2014.

1.7. Selected Large Springs in LAKE

Two springs have been selected for monitoring in LAKE (Table 6): Blue Point Spring and Rogers Spring. The locations of these springs are shown in Figure 15.

Table 6. Discharge and water quality data for RCA springs in LAKE. Data from Sada and Jacobs (2008a).

Spring	Discharge (m ³ /day)	Temperature (°C)	Diss. Oxygen (mg/L)	pH (Standard Units)	Specific Conductance (µS/cm)
Blue Point Spring	>720	29.5	2.71	7.2	4,170
Rogers Spring	>1440	29.8	2.34	7.2	3,736

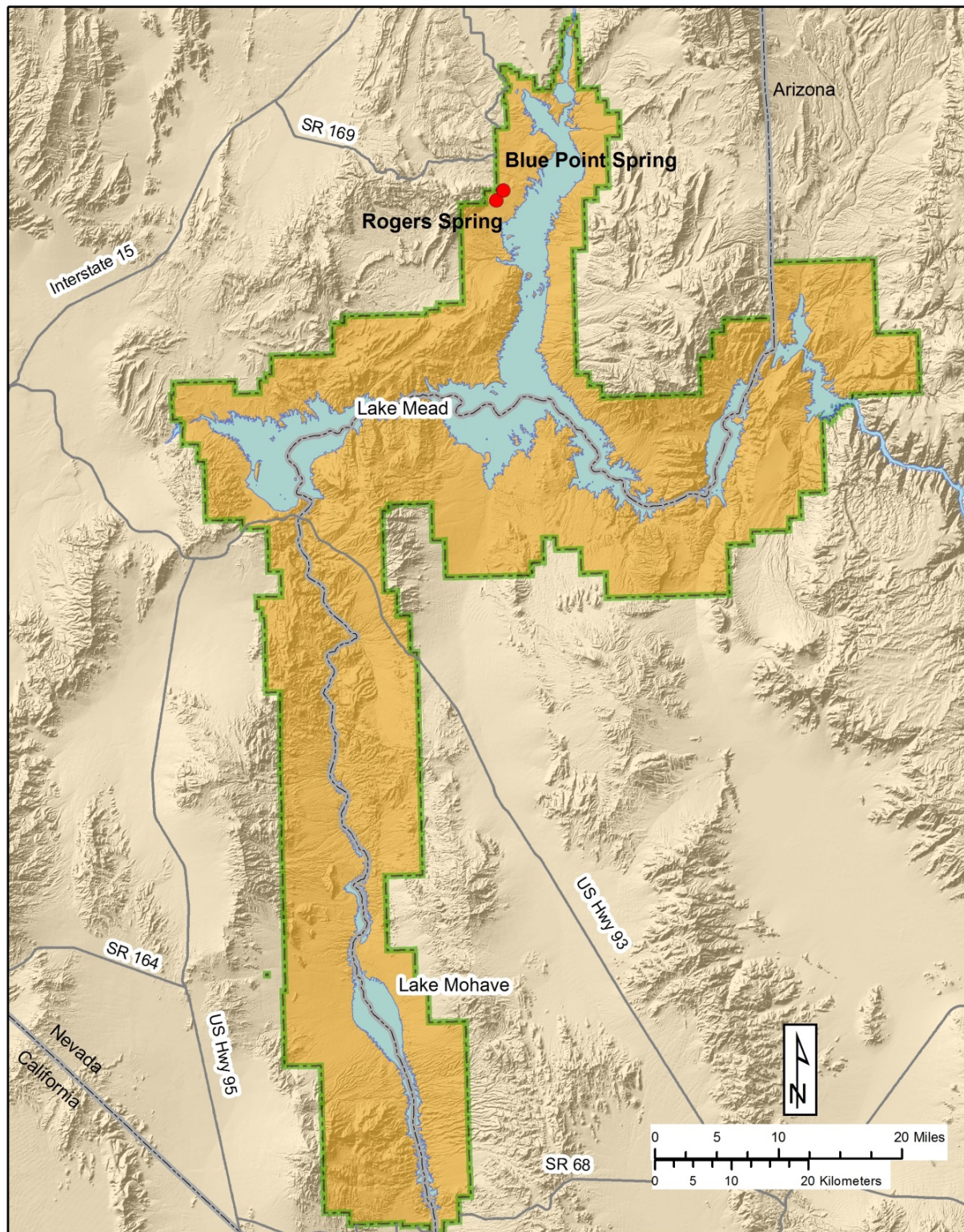


Figure 15. Map of springs selected for monitoring in LAKE.

1.7.1. Blue Point Spring

Location and Description: Blue Point Spring consists of a pool that spills into a springbrook hundreds of meters long (Figure 16).

Site History: The pool and the springbrook are separated by a weir (a dam that controls the pool level) that was gaged by the USGS from 1999 to 2012 (station #09419547; Figure 17). The USGS ceased gaging the station at the end of Water Year 2012 due to funding constraints. MOJN I&M has been monitoring the weir since early 2013.

Fauna: The spring hosts three species of snails (*Assimenea* Sp., *Pyrgulopsis coloradensis*, and *Tryonia* Sp.) in different habitat niches (D. Sada personal communication). It also hosts an invasive snail species and invasive fish. Blue Point Spring is the location of one of a handful of extant natural populations of relict leopard frog (*Rana onca*).



Figure 16. Blue Point Spring in LAKE in February 2012. The weir is visible in the top left.

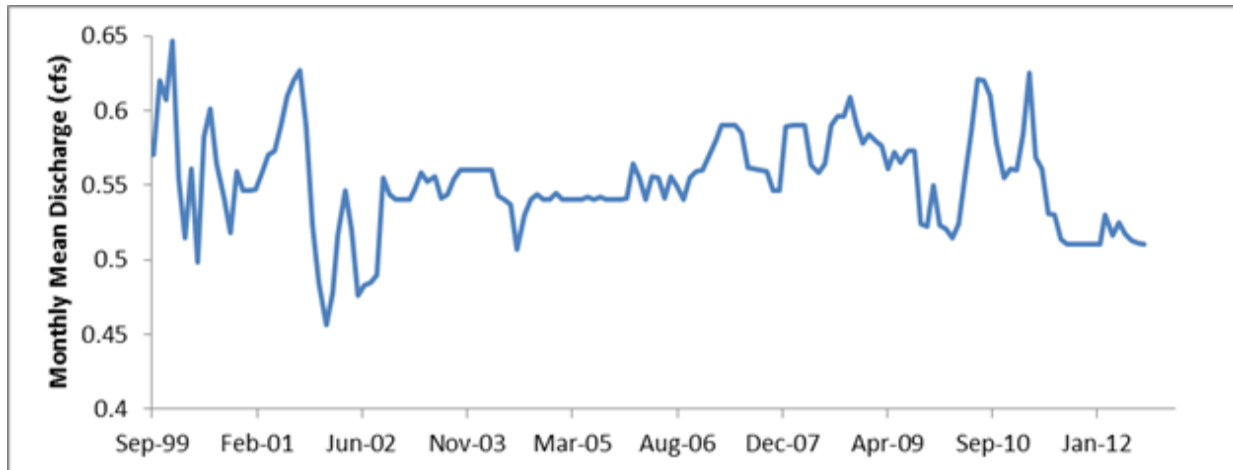


Figure 17. Monthly mean discharge at USGS gage at Blue Point Spring, Water Years 2000-2012.

1.7.2. Rogers Spring

Location and Description: Rogers Spring consists of a 25 meter by 25 meter concrete bathing pool (Figure 18). Water spills from the pool into a springbrook hundreds of meters long.

Site History: Rogers Spring has been highly disturbed by human use, in particular the construction of the bathing pool by the Civilian Conservation Corps in the 1930s. The spring's discharge has been gaged by the USGS since 1985 (station #09419550; Figure 19). From 1985 to 1998, the gaging station was located in the springbrook below the pool, downstream of a broad-crested weir. In December 1998, a 9-inch (22.9-centimeter) Parshall flume was installed in the springbrook (Werrell 1999). The discharge record exhibits less variability since the installation of the flume (Figure 19).

Fauna: The aquatic ecology of the pool is dominated by aquarium fish and turtles released by park visitors. The springbrook is the location of one of a handful of extant natural populations of relict leopard frog (*Rana onca*).



Figure 18. Rogers Spring at LAKE in December 2009.

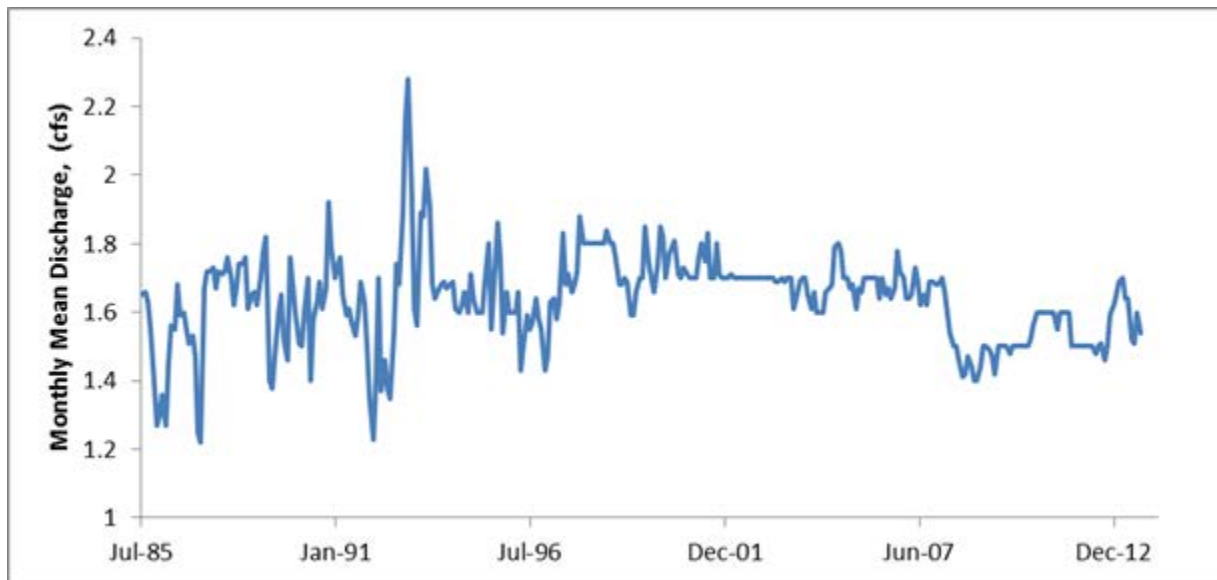


Figure 19. Monthly mean discharge at USGS gage at Rogers Spring, Water Years 986-2013.

1.8. Selected Large Spring in MOJA

One spring has been selected for monitoring in MOJA (Table 7): MC Spring. The location of this spring is shown in Figure 20.

Table 7. Discharge and water quality data from selected large springs in MOJA. Data from B. Poff.

Spring	Discharge (m ³ /day)	Temperature (°C)	Diss. Oxygen (mg/L)	pH (Standard Units)	Specific Conductance (µS/cm)
MC Spring	not measured	24.4	8.18	8.84	4,600

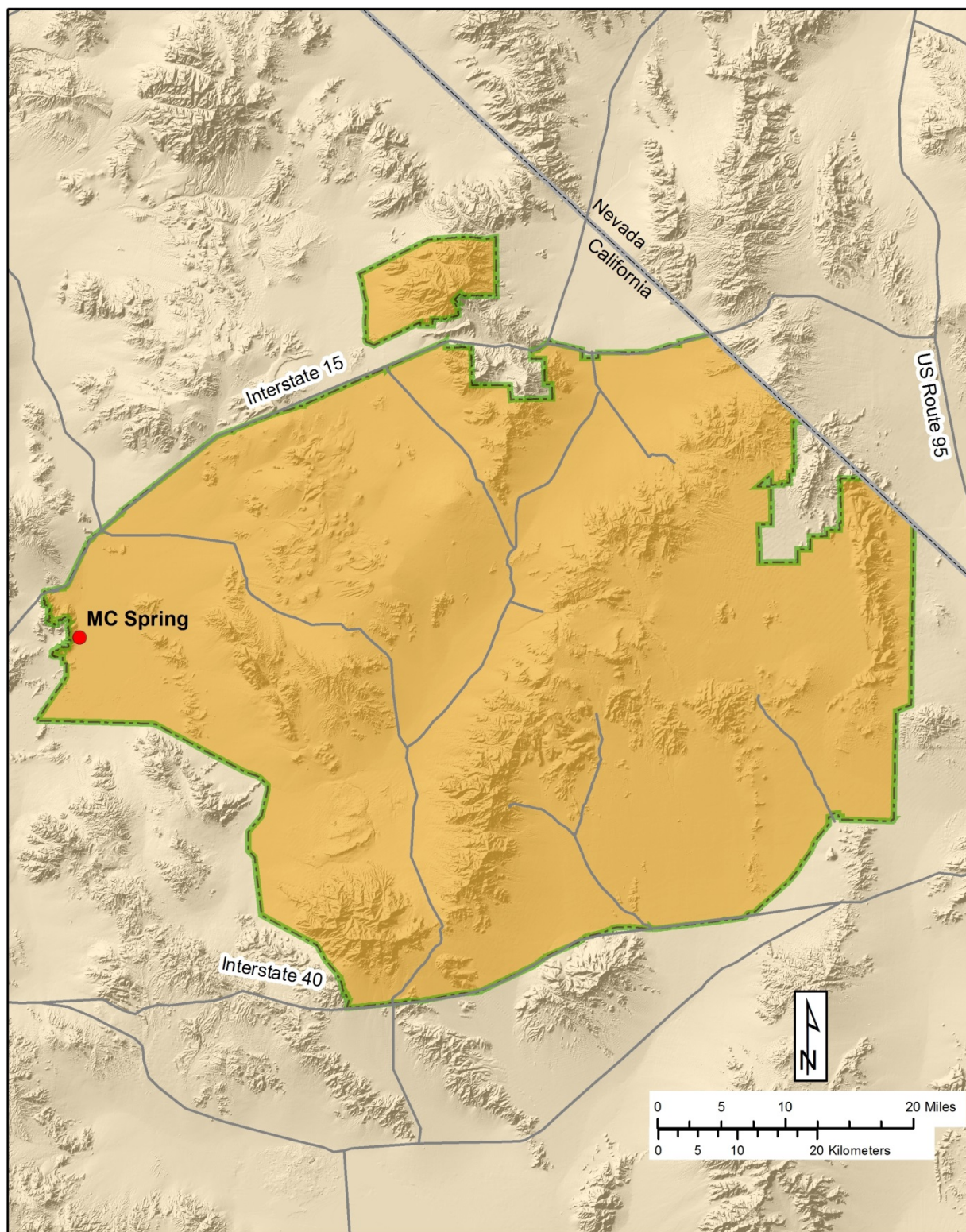


Figure 20. Springs selected for monitoring in MOJA.

1.8.1. MC Spring

Location and Description: MC Spring is located at Zzyzx, a former resort and spa currently operated as a research center. There are a number of springs near Zzyzx, and they are sometimes collectively referred to as Zzyzx Springs or Soda Springs. MC Spring is a small, limnocrene spring with no outlet (Figure 21). Vegetation is removed as needed to maintain the pond as an open-water fish habitat. The spring's entire discharge is consumed by ET and direct evaporation.

Site History: The springs at Zzyzx were used for a variety of purposes in the 19th and 20th centuries (Woo and Hughson 2003), but there is no evidence of direct diversion from MC Spring. However, as Woo and Hughson (2003) state:

“The fact that cattails and sedges in MC Spring must be cut back about every 18 months or so suggests that the existence of this open pool of water, with a surface area of 250 square feet [23.2 square meters] and a volume of 1,000 cubic feet [28.3 cubic meters], is anthropogenic.”

Fauna: MC Spring gets its name from the Mohave tui chub (*Siphateles bicolor mohavensis*), a federally-listed endangered desert fish species. The Mohave chub was extirpated from the Mojave River in the 1960s, and MC Spring is one of its last remaining natural habitats (Henkanaththegedara et al. 2008). The spring is also an important water source for desert bighorn sheep (*Ovis canadensis nelsoni*).



Figure 21. MC Spring in MOJA in April 2010.

1.9. Selected Large Springs in PARA

Two springs have been selected for monitoring in PARA: Pakoon Springs and Tassi Spring. The locations of these springs are shown in Figure 22.

Table 8. Discharge and water quality data for selected large springs in PARA. Data from Sada and Jacobs (2008b).

Spring	Discharge (m ³ /day)	Temperature (°C)	Diss. Oxygen (mg/L)	pH (Standard Units)	Specific Conductance (µS/cm)
Pakoon Springs	382*	19.5*	3.86*	7.6*	522*
Tassi Spring	144	25.0	6.00	7.8	500

* The values given in this table for Pakoon Springs are the sum of the discharges and the median water quality values measured by Sada and Jacobs (2008b) at the various spring outlets.

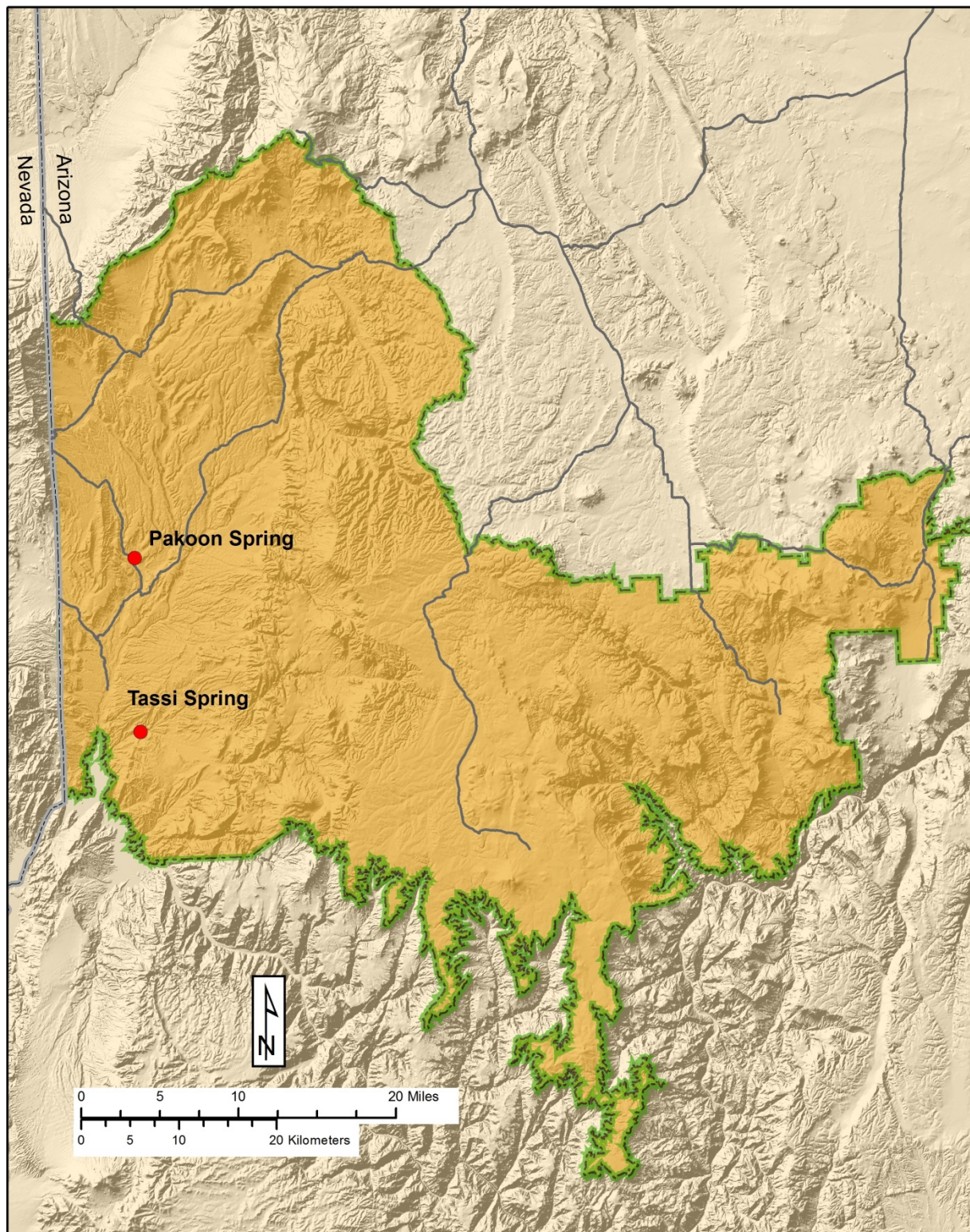


Figure 22. Springs selected for monitoring in PARA.

1.9.1 Pakoon Springs

Location and Description: Pakoon Springs currently consist of a large (~1 hectare) marshy area consisting of several “arenas” with small outflows, a reed-dominated pool (Figure 23), and a riparian corridor in the wash bottom approximately 1 kilometer long.

Site History: The entire discharge of Pakoon Springs was used for agriculture until the 1980s. All spring outflows were diverted to a reservoir behind a dam, and from there to an irrigation system. An extensive restoration program was initiated in 2006 to restore biodiversity and ecological function (BLM 2007). Restoration included extensive re-grading, the diversion of flow from the reservoir into a nearby wash, the establishment of a riparian corridor in that wash, the excavation and removal of all diversion structures, the eradication of invasive species, and the re-establishment of wetlands at outflows. Further restoration work in Spring 2015 included removal of the pool and recontouring of the surrounding area (Figure 23).

Fauna: The native Woodhouse’s toad (*Bufo woodhousii*) and the non-native bullfrog (*Rana catesbiana*) are found in Pakoon Springs. Arizona Game and Fish is actively attempting to eradicate bullfrogs from the spring.



Figure 23. Source of Pakoon Spring in April 2015, immediately after completion of Spring 2015 restoration activities. Photo by J. Fox.

1.9.2. Tassi Spring

Location and Description: Tassi Spring is located on the historic Tassi Ranch, one of PARA’s most important cultural resources. Water seeps from many locations in the ranch area, but the only discrete spring outlet with flowing water is the one that flows into an irrigation canal on the hill slope behind the ranch buildings (Figure 24). It is this outlet that will be monitored in this protocol.

Site History: All of Tassi Spring’s outlets were diverted during the era that the ranch was in use (1936-1996), and these diversions still control the spring today. The spring’s vegetation is actively managed, both to preserve the irrigation canal as a cultural resource and to provide aquatic habitat.

Fauna: The irrigation canal contains a population of Grand Wash springsnails (*Pyrgulopsis bacchus*; Sada 2005) that are endemic to a small number of springs in the Grand Wash drainage. The spring is also being used as a refugium for the relict leopard frog (*Rana onca*).



Figure 24. Irrigation canal at Tassi Spring in PARA in April 2010. Photo by J. Fox.

1.10. Monitoring Wells in MOJN Parks

Monitoring wells were selected for the SLS protocol based on the following criteria:

- they were installed to specifically to monitor water levels in locations believed to be relevant to the discharge of springs in the parks, and
- they are not being monitored by another entity.

The only wells that meet these criteria are the Baker Creek Road well in GRBA and the Rogers Bay well in LAKE.

1.10.1. Baker Creek Road Well in GRBA

The Baker Creek Road well was installed in 2012, with funding provided through the Southern Nevada Public Lands Management Act (Round 8 Conservation Initiatives Project “Evaluation of Basin Fill Aquifers in Southern Spring and Snake Valleys”, NP60). The well site is located to the east of the sewage lagoons near Baker Creek Road (Figure 25). The wellbore, which was completed to a depth of 161.7 feet (49.3 meters) below ground surface, contains three nested monitoring wells (Table 9), all of which are included in the SLS protocol. Details on well construction and the well log are presented by Prudic (2013).

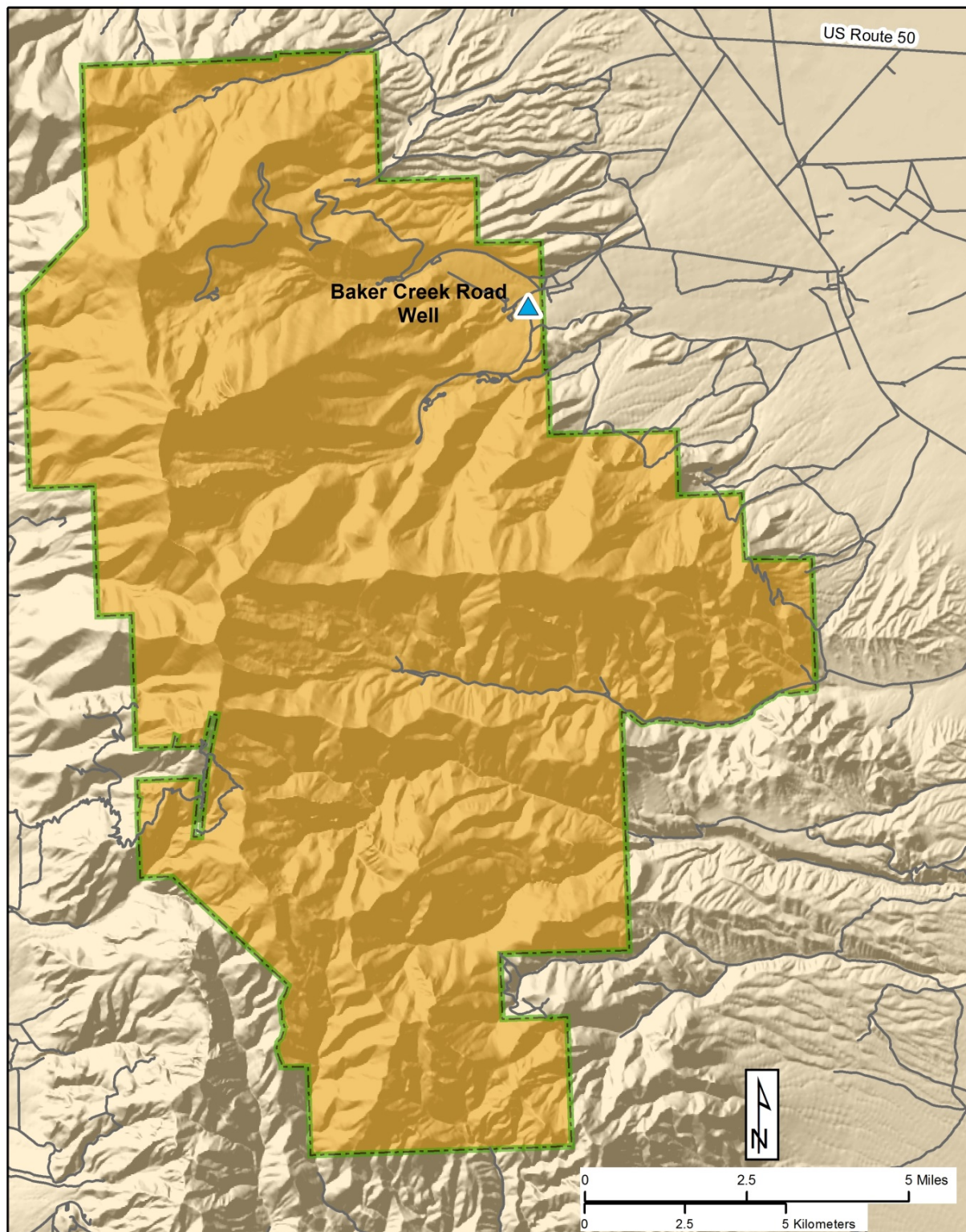


Figure 25. Well selected for monitoring in GRBA.

Table 9. Screen intervals and depths-to-water for nested wells in the Baker Creek Road well in GRBA. All information from Prudic (2013).

Well	Nominal Screen Interval (ft below land surface)	Depth-to-water at time of completion (ft below land surface)
Well 3	31-71 (9.4-21.6 m)	43.1 (13.14 m)
Well 2	110-120 (33.5-36.6 m)	41.7 (12.71 m)
Well 1	155-160 (47.2-48.8 m)	23.5 (7.16 m)

1.10.2. Rogers Bay Well in LAKE

Rogers Bay Well was installed by the USGS in 2011 near North Shore Drive in LAKE (Figure 26). The well is 973 feet (296.6 meters) deep, and USGS measurements between 2011 and 2013 showed that the water level stabilized at 276 to 277 feet (84.1 to 84.4 meters) below ground surface. A report describing this well is in preparation by the USGS (J. Wilson personal communication).

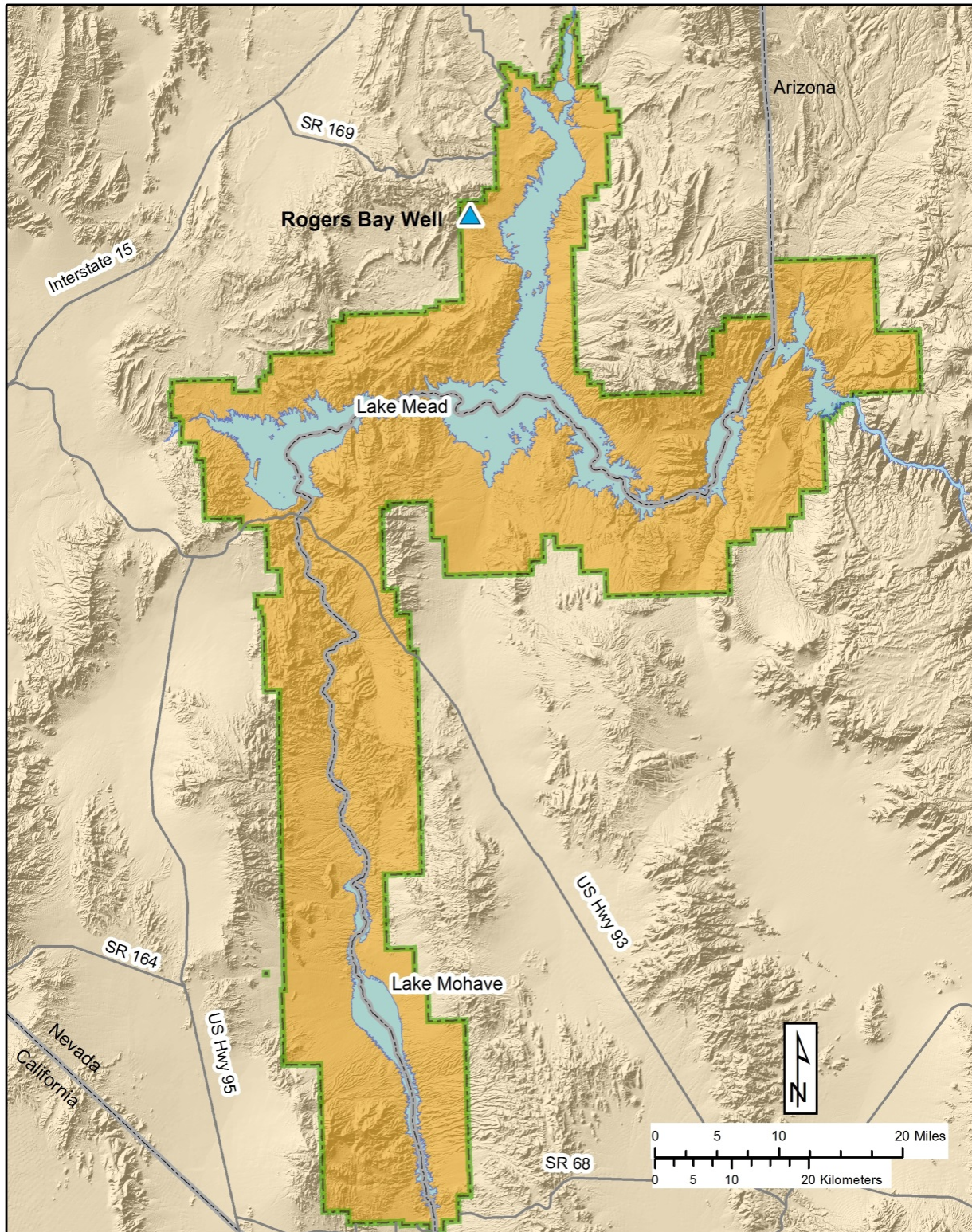


Figure 26. Well selected for monitoring in LAKE.

1.11. Objectives

The overarching programmatic goal of the MOJN I&M is to obtain information that will aid in the assessment, conservation, and restoration of water resources. Monitoring objectives for the Vital Signs are defined as *monitoring questions* that identify conceptual and management issues. *Measurable objectives* link monitoring questions to data collection.

1.11.1. Special Issues Related to Selected Large Springs

Groundwater Withdrawal

In many cases, the aquifers that are the sources of the selected large springs are viewed as potential targets for groundwater extraction. If the human population in the region continues to increase and the discharge from the Colorado River continues to decrease (Barnett and Pierce 2008), then it is likely that there will be increased use of these resources for municipal, agricultural, and industrial water supply.

The Southern Nevada Water Authority has applied for groundwater rights in a number of basins in east-central Nevada, and has put forward plans for large-scale groundwater withdrawals in that region. The plan includes pumping groundwater from the valleys adjacent to GRBA, which could potentially have impacts on park water resources, including Rowland Spring (Elliott et al. 2006).

Numerous solar energy plants have recently been proposed for the Mojave Desert, including several in the Amargosa Valley and surrounding area to the east of DEVA and one in the Soda Mountains west of MOJA. There are several solar technologies with different water requirements, but wet-cooled solar plants in the Mojave Desert could each potentially withdraw thousands of cubic meters per day from groundwater (EPG 2010).

Large-scale groundwater withdrawal creates cones of depression in the water table, which can lower the water level at springs, reducing discharge or eliminating it entirely. These changes can result in the extinction of species that are endemic to the springs (e.g., Hershler et al. 2014). In large aquifers with low recharge rates, it can take centuries for water levels to recover after pumping is discontinued (Bredehoeft and Durbin 2009).

Endemic and Endangered Species

Sada et al. (2005) estimate that springs in the western United States support several hundred endemic plant and animal species, some of which are listed as endangered. The selected large springs in the MOJN parks provide habitat to a number of these species.

The Mohave Chub (*Siphateles bicolor mohavensis*) is a federally-listed endangered fish species, and MC Spring in MOJA is one of only four remaining locations where it can be found (Henkanaththegedara et al. 2008). Saratoga Springs supports the Saratoga Springs pupfish (*Cyprinodon nevadensis nevadensis*), an endemic species (e.g., Moyle et al. 1995).

Springsnails (Hydrobiidae) exhibit a high degree of endemism, with DNA analysis suggesting much greater genetic differences in springsnail populations between springs than can be determined by examining specimens (Liu et al. 2003). The springsnail genera present in the selected large springs in

the MOJN parks are *Pyrgulopsis*, *Tryonia*, and *Ipnobius* (Table 10). *Pyrgulopsis* generally prefers cooler water, although some species have adapted to warmer springs, while *Tryonia* and *Ipnobius* are found in warm springs (Sada 2009). The NPS, Bureau of Land Management, and Fish and Wildlife Service signed a Memorandum of Understanding (since outdated) with conservation groups in 1998 recognizing the importance of conserving springsnail fauna in the Great Basin (Averill-Murray 2008). As of 2014, the status of 32 hydrobiid species was under review by the Fish and Wildlife Service (Docket No. FWS–R8–ES–2011–0001), including *P. Coloradensis* (found in Blue Point Spring) and *T. Variegata* (found in Saratoga Spring).

Table 10. Springsnail populations in the selected large springs in the MOJN parks.

Spring	Pyrgulopsis	Tryonia	Ipnobius
Texas		<i>I. robusta</i> was previously identified as <i>T. robusta</i>	<i>I. robusta</i> (Moret et al. 2014a))
Travertine		<i>I. robusta</i> was previously identified as <i>T. robusta</i>	<i>I. robusta</i> (Hershler and Liu 2008)
Nevares		<i>I. robusta</i> was previously identified as <i>T. robusta</i>	<i>I. robusta</i> (Hershler and Liu 2008)
Saratoga	<i>P. amargosae</i> (Hershler and Liu 2008), <i>P. Sanchezi</i> (Hershler et al. 2013)	<i>T. variegata</i> (Hershler et al. 1999)	
Grapevine Complex*	<i>P. perforata</i> , <i>P. sanchezi</i> , <i>P. sp.</i> (undescribed) (Hershler et al. 2013)	<i>T. margae</i> , <i>T. rowlandsi</i> (Hershler et al. 1999)	
Tassi	<i>P. bacchus</i> (Sada 2005)		
Blue Point	<i>P. coloradensis</i> (Sada 2005)	<i>T. sp.</i> (D. Sada, personal communication)	

*It is not known which, if any, of these taxa are present in Mound Spring.

The selected large springs in DEVA are known to harbor endemic macroinvertebrates in addition to springsnails. Nevares Springs harbors nine endemic aquatic invertebrate species, one of which, the Nevares Springs naucorid bug (*Ambrysus funebris*), is a candidate for protection under the Endangered Species Act (Whiteman and Sites 2008). Three rare insect species occur at Saratoga Spring (Threloff 1998): the Saratoga Springs belostomatid bug (*Belostoma saratogae*), the Amargosa naucorid bug (*Pelocoris shoshone amargosus*), and the Death Valley June beetle (*Polyphylla erratica*). It is possible that endemic species and subspecies of invertebrates may occur in the other selected large springs in the MOJN parks that have not been as carefully investigated.

The relict leopard frog (*Rana onca*) was believed to be extinct until it was rediscovered in 1991 (Jaeger et al. 2001). A handful of natural populations remain, all within LAKE. The most recent published population estimate is 1100 adult individuals (RLFCT 2005). Two of the remaining populations are in selected large springs in LAKE: Blue Point Springs and Rogers Spring. Introduced populations have been established in a number of additional sites (including Tassi Spring in PARA) as part of an experimental program established by a voluntary multi-agency Conservation Agreement and Strategy (RLFCT 2005), and it is possible that the frogs could be reintroduced to other selected

large springs in the future. Threats to the relict leopard frogs include reduced discharge at springs, altered habitat at springs, chytrid fungus, and introduced species such as bullfrogs (*Rana catesbeiana*) and crayfish (*Procambarus clarkii*) (Jennings and Hayes 1994). Bradford et al. (2004) studied two recent population extinctions, and discovered that the cause at both sites was likely the encroachment of vegetation on open water habitat.

Numerous populations of springsnails, fish, and other species have been extirpated from springs in the western U.S. due to anthropogenic habitat changes (Sada and Vinyard 2002), including groundwater withdrawal (e.g., Myler et al. 2007). The water quality and spring discharge monitoring in this protocol will permit the detection of any habitat degradation that could threaten endemic and endangered species in the selected large springs in the MOJN parks.

Spring Restoration

Large springs are among the only reliable sources of water in the Mojave Desert, so many of them have historically been diverted into water supply systems for agricultural or residential use, significantly impacting or eliminating the aquatic habitat they support. For example, Texas Springs in DEVA has a springbrook roughly 1 km in length, but the springbrook historically flowed 5 km to the valley floor playa (Threlhoff and Koenig 1999). The MOJN parks are currently rehabilitating or considering rehabilitating several of the selected large springs.

Pakoon Springs and Tassi Spring in PARA were highly altered to divert water for agricultural purposes. It has been determined that the irrigation canal at Tassi Ranch is an important cultural resource, and any future work at the site will leave it intact. However, as described above, Pakoon Springs was extensively altered in an attempt to restore the flow system to a state closer to its natural condition, and further rehabilitation is planned.

Most of the water from Texas, Travertine, and Nevares Springs in DEVA has been diverted for a century. Recently, the NPS has made efforts to restore more of this water to natural springbrooks, in some cases restoring springs that have not flowed for decades. Planning for final restoration of these springs is ongoing (e.g., Sada and Cooper 2012).

Monitoring is important in spring rehabilitation to observe the effect of the changes on aquatic habitat and to determine whether the spring is discharging in the planned locations. The monitoring data collected in this protocol can be used to assess the long-term success of the rehabilitation efforts in these springs.

Climate Change

Global climate change has already altered the climate of the Southwestern United States. In particular, average daily temperatures are increasing (Menne and Williams 2009), heat waves are more frequent (Hoerling et al. 2014), the region has experienced frequent severe droughts since 2001 (McDonald 2010), snowpacks are reduced (Mote et al. 2005), and snowmelt is occurring earlier (Stewart et al. 2005).

A recent NPS study compared recent climate data in each park unit with the historical record (Monahan and Fisichelli 2014). Six MOJN units were included in the study: DEVA, GRBA, JOTR,

LAKE, MANZ, and MOJA. In all six parks units, recent temperatures were among the warmest on record, with higher temperatures observed in both summer and winter, and fewer frost days than in any other period. The precipitation results were less unequivocal (the studies methods were intended to look at long term change rather than the recent drought), but JOTR was observed to be in a prolonged, multi-decadal period of reduced precipitation.

In general, springs fed by large aquifers are resilient to changes in surface water hydrology, as they respond very slowly to changes in recharge rates. However, springs fed by local recharge are vulnerable to drought, with changes ranging from lower discharges and reduced aquatic habitat to seasonal or year-round drying. At all springs, increased temperatures can lead to increases in water temperature, increases in water use by existing vegetation, changes in vegetative communities, and changes in patterns of wildlife use.

1.11.2. Monitoring Questions

Spring hydrology includes both surface water and groundwater, so springs monitoring addresses three MOJN I&M vital signs that are central to this protocol: Surface Water Dynamics, Surface Water Chemistry, and Groundwater Dynamics and Chemistry. In addition, the group that selected the vital signs intended that the protocol for springs should include an aquatic biota monitoring component (Table 5.1, Chung-MacCoubrey et al. 2008). These goals are addressed by considering the following questions:

1. Is the hydrology of any of the selected large springs in the MOJN parks changing?
2. Is the overall ecological condition of any of the selected large springs in the MOJN parks changing?

1.11.3. Measureable Objectives

In light of these questions and the broader goals outlined above, this protocol will address the following specific measurable objectives:

1. Determine the status, trend, and range of variability of the discharge of each of the selected large springs.
2. Determine the status, trend, and range of variability of water levels in existing monitoring wells completed in the vicinity of the selected large springs.
3. Determine the status, trend, and range of variability of water quality parameters (pH, temperature, dissolved oxygen, and specific conductance) and chemical constituents in each of the selected large springs.
4. Determine the status, trend, and range of variability of metrics calculated from the macroinvertebrate assemblages in each of the selected large springs.
5. Determine the status, trend, and range of variability of the population and spatial extent of springsnails within each of the selected large springs that they inhabit.

Figure 27 illustrates how the data collected will be used to achieve the measurable objectives, how we anticipate that the resulting information on status and trends will be used to address monitoring questions, and examples of how the monitoring questions relate to park management issues beyond the scope of the protocol.

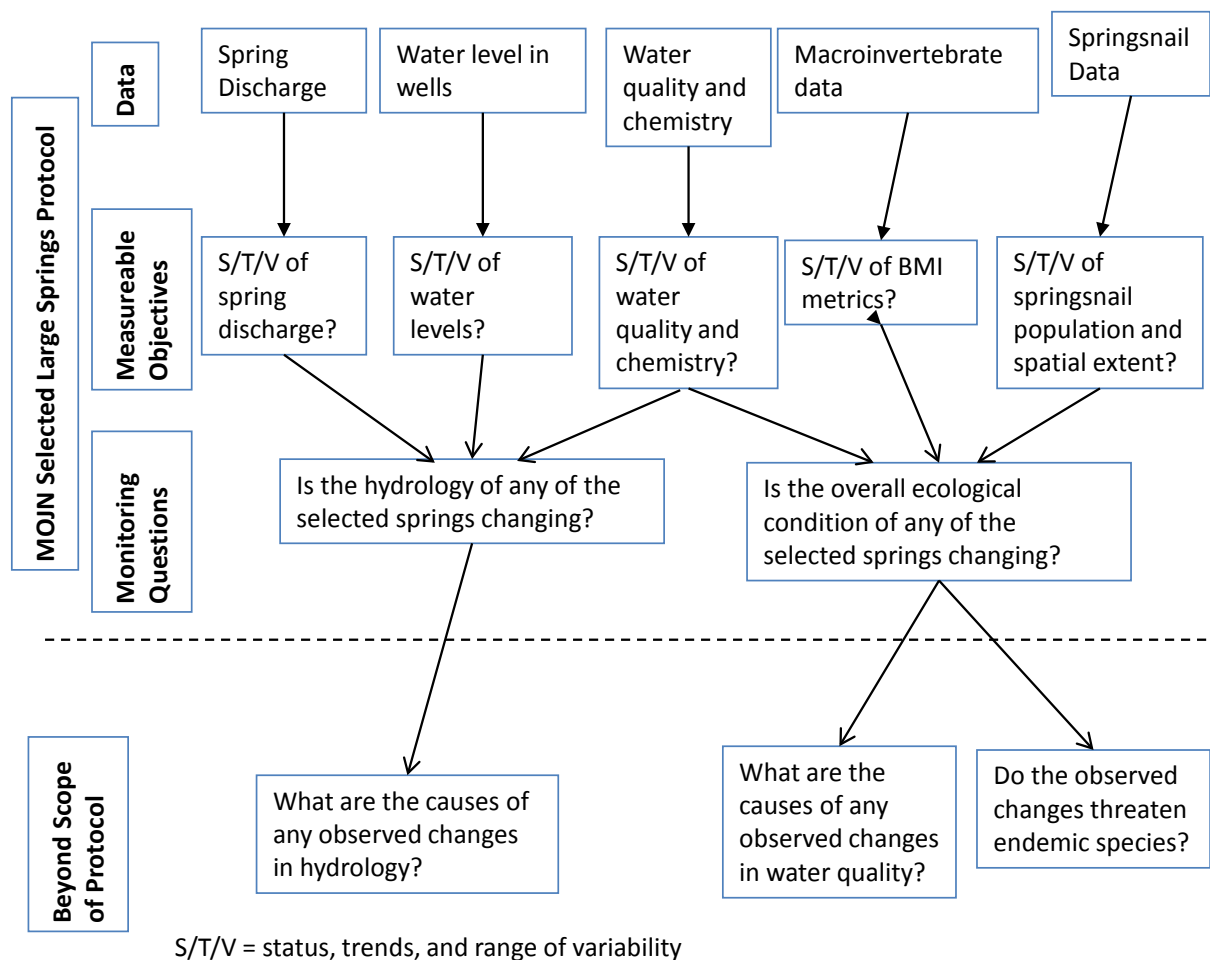


Figure 27. Overview of the relationships among data, measurable objectives, monitoring questions, and park management issues. The objective of the MOJN I&M Selected Large Springs protocol is to collect the data and address the questions shown above the dashed line.

1.11.4. Potential Integration with Other Protocols

One of MOJN I&M's priority vital signs is riparian vegetation (Chung-MacCoubrey et al. 2008). MOJN I&M plans to develop a Riparian Vegetation (RV) monitoring protocol in the coming years. At this time, MOJN I&M plans to include the springs monitored in the SLS protocol among the sites monitored in the RV protocol. The quarterly visits to springs by the SLS crew could provide valuable synoptic data at these sites with a frequency that would otherwise be logistically infeasible.

As this protocol has not been developed, it is not clear what form the integration of the monitoring results will take.

As part of MOJN I&M's Invasive Plants Early Detection vital sign, MOJN I&M staff engaged in field activities related to the Selected Large Springs protocol will report any observations of invasive plants on the Early Detection list to the MOJN ecologist and to park managers.

The springs selected for monitoring in GRBA discharge into stream drainages, and the perennial streams in GRBA monitored in the MOJN I&M Streams and Lakes protocol are all fed by springs. Springflow is particularly important in determining the streams' late-summer discharge and water quality. It is likely that the results of the SLS protocol monitoring will be discussed in the quadrennial trend reports for the MOJN I&M Streams and Lakes protocol and vice versa.

2. Sampling Design

2.1. Overview of Sampling Design

The MOJN I&M SLS protocol will monitor 15 springs in DEVA, GRBA, JOTR, LAKE, MOJA, and PARA (Table 11). These springs have been selected in consultation with park managers, and data from different springs will not be combined to make inferences regarding a larger population. Each spring will be visited quarterly (with fewer visits for GRBA springs, where winter access is difficult), with park staff performing the quarterly monitoring at DEVA and GRBA. The quarterly monitoring will consist of water quality measurements and some measurement of spring discharge. Every two years, water samples and benthic macroinvertebrate samples will be collected from most springs, and springsnails will be monitored at those springs with extant populations.

While the sampling design calls for quarterly visits to springs, the data collection, data management, and data analysis procedures do not require specific sampling dates. Thus, it would be possible to visit the springs after major storms, fires, or other disturbances to collect timely data.

Two wells will also be monitored in GRBA and LAKE. These wells were selected because they were installed to specifically to monitor water levels in locations believed to be relevant to the discharge of springs in the parks, and they are not being monitored by another entity. The water level at each well will be monitored quarterly, with park staff performing the monitoring at GRBA.

Table 11. Overview of SLS protocol monitoring at each selected spring.

Park	Monitoring Wells	Spring	Staff for Quarterly Visits	Quarterly Water Quality	Biennial Water Chemistry	Spring Discharge	Biennial Snail Monitoring	Biennial BMI Sampling
MOJA	No	MC	MOJN I&M	Yes	Yes	Continuous pool stage	No	No
PARA	No	Pakoon	PARA	Yes	Yes	TBD	No	Yes
		Tassi	PARA	Yes	Yes	Quarterly discharge	Yes	Yes
JOTR	No	49 Palms	MOJN I&M	Yes	Yes	Quarterly open water area	No	Yes
		Smith Water Canyon	MOJN I&M	Yes	Yes	Quarterly springbrook length	No	Yes
DEVA	No	Texas	DEVA	Yes	Yes	Continuous discharge ¹	Yes	Yes
		Travertine	DEVA	Yes	Yes	Continuous discharge ¹	Yes	Yes
		Nevares	DEVA	Yes	Yes	Continuous discharge ¹	Yes	Yes
		Saratoga	DEVA	Yes	Yes	Continuous pool stage ¹	Yes	Yes
		Mound	DEVA	Yes	Yes	Continuous discharge ¹	Yes	Yes
GRBA	Yes (Baker Creek Road Well))	Boiler	GRBA	Yes	Yes	Discharge, twice a year ²	No	Yes
		Marmot	GRBA	Yes	Yes	Discharge, three times a year ²	No	Yes
		Strawberry Source	GRBA	Yes	Yes	Discharge, twice a year ²	No	Yes
LAKE	Yes (Rogers Bay Well)	Blue Point	MOJN I&M	Yes	Yes	Continuous discharge	Yes	Yes
		Rogers	MOJN I&M	Yes	Yes	USGS gage	No	No

¹. The discharge of DEVA springs will be monitored by DEVA staff in cooperation with NPS WRD.

². The discharge of GRBA springs will be measured by GRBA crews in cooperation with MOJN staff.

2.2. Response Design

The sample response design of the SLS protocol is somewhat unusual in that the protocol is designed to monitor individual springs identified as high priority by park managers. Because data from different springs will not be combined to make inferences regarding a larger population, it is possible to tailor monitoring solutions to individual sites where standard methods are inappropriate. The rationale and the response design for each of the chosen monitoring parameters is described below

2.2.1. Spring Discharge

Rationale: Spring discharge is the master variable in spring ecology (e.g., Meyer et al. 2003; von Fumetti et al. 2006). The amount and variability of a spring's discharge control the type and extent of different aquatic habitats, the substrate of the springbrook, the type of riparian plants that can be supported, and the availability of water to wildlife.

Response Design: Power analyses using historical data (Section 2.4) indicate that quarterly discharge measurements are sufficient to detect long-term trends in some large springs. However, continuous discharge measurements are desirable because they fully characterize seasonal variability, increasing the power of a data set to detect changes in seasonal discharge patterns. Therefore, we will monitor discharge continuously at the springs where it is possible.

Because of the heterogeneity of spring environments, no single discharge monitoring method can be used in all springs. Instead, six different methods will be used.

Continuous discharge using a flume or weir: Permanent flow monitoring structures have been installed at Pakoon Springs, Texas Springs, Travertine Springs, Nevares Springs, Mound Spring, Blue Point Spring, and Rogers Spring. At these structures, the relationship between discharge and water level is a known relationship, so the continuous water level record obtained from a pressure transducer can be converted to discharge.

Continuous pool stage: MC Spring is a limnocrone spring that does not discharge to a springbrook. Water seeps into the ponds and is lost to evapotranspiration, meaning that conventional discharge measurements are impossible. Instead, pool stage will be continuously monitored using a pressure transducer.

Saratoga Spring has numerous sources within a large (~7 ha) wetlands area. While there is a distinct springbrook between one set of sources and the excavated pools, it flows through an area of dense reeds with little topographic relief. If a temporary or permanent weir or flume were placed on the springbrook, the discharge would flow through a different part of the reeds. Therefore, pool stage will be continuously monitored in the springbox using a pressure transducer.

While pool stage data are not directly comparable to the discharge estimates, they can be used to detect changes, and to assess if fish habitats are threatened.

Quarterly discharge measurements: At some springs it is not feasible to install a flume or weir. Specifically:

- Tassi Spring discharges into an irrigation canal that is a recognized cultural resource.
- Boiler Spring, Marmot Spring, Strawberry Source Spring, Smith Water Canyon Springs, and Fortynine Palms Oasis are located in steep mountainous areas. Any flumes and pressure transducers installed in these washes would be swept downstream and/or buried during high-intensity storm events or spring runoff.

Given the limited resources available for the protocol, these springs cannot be visited more frequently than quarterly. Many springs in GRBA cannot be accessed safely in the winter, so Boiler Spring and Strawberry Source Spring will be monitored twice a year and Marmot Spring will be monitored three times a year.

Quarterly estimate of open water area: Fortynine Palms Oasis consists of a series of pools that do not generally discharge to a springbrook. Unlike MC Spring and Saratoga Spring, however, it is located in a steep wash that experiences frequent scouring events. The USGS attempted to use a pressure transducer to record pool level in Fortynine Palms Oasis, but lost their instrumentation in a flash flood. They concluded that further attempts at continuous monitoring of the site were impractical. Therefore, MOJN I&M will conduct quarterly visits to the site to count the number of pools and estimate the total open water area. While this number is not directly comparable to the discharge estimates, it can be used to detect changes, and will be valuable in assessing the availability of water to wildlife.

Quarterly estimate of springbrook length: Smith Water Canyon Springs consists of five pools along a wash. During the wet season, flow from these pools forms springbrooks that are up to approximately 40 meters long. The discharges of these springbrooks are difficult to measure accurately because they are small (decreasing to zero during the dry season) and they do not flow in defined channels, making it difficult to capture the flow for a volumetric measurement. Therefore, the springbrook length below each pool is measured instead.

2.2.2. Water Quality

Rationale: The following four parameters have been identified by NPS Water Resources Division (WRD) as critical “core parameters” to be monitored in aquatic habitats. Springs with different water quality parameters have been found to have different benthic macroinvertebrate assemblages (Myers and Resh 2002).

Water temperature controls many physical, chemical, and biological processes. In springs, water temperature generally becomes closer to atmospheric temperature and more variable further from the spring source, which, along with similar longitudinal gradients in water chemistry, creates a gradient in habitat conditions. Increased variation in water temperature with distance from the spring source has been found to have a strong influence on macroinvertebrate communities (e.g., Smith et al. 2003; von Fumetti et al. 2007).

The pH of a water body is a measure of its hydrogen ion activity, which controls many chemical and biological processes.

Specific conductance (SpCond, the temperature-corrected equivalent of raw electrical conductivity) is the measure of a waters' ability to conduct an electrical current and provides a broad measure of the concentration of ions in a water sample. Similarities or differences in specific conductance can be used to determine whether springs are fed by the same aquifer or have different sources (Elliott et al. 2006).

Dissolved oxygen (DO) sustains aquatic communities that respire aerobically, including zooplankton, algae, amphibians, and fish. DO is often very low or absent in groundwater, but concentrations increase once the water is discharged to springs and exposed to the atmosphere. As systems become more productive, biota consume oxygen from the water column at an increasing rate. However, high rates of photosynthesis by aquatic plants and algae can result in springs with DO levels higher than would be observed in water bodies in equilibrium with the atmosphere (e.g., YSI Environmental 2005).

Response Design: The core water quality parameters (temperature, pH, DO, and specific conductance) required by WRD will be measured quarterly at each selected large spring using a handheld multiprobe water quality instrument. This frequency should be sufficient to determine the approximate magnitude of any seasonal variations in water quality.

2.2.3. Water Chemistry

Rationale: Major ions and nutrient concentrations will be measured by laboratory analysis of water samples.

Major ions (Ca^{2+} , Na^+ , Cl^- , Mg^{2+} , K^+ , SO_4^{2-} , and HCO_3^-) are important in understanding the geochemical evolution of surface waters. They are generally controlled by interactions between groundwater and the aquifer materials, so they are useful in understanding the flow paths taken by spring water (e.g. Schaefer et al. 2005). Changes in the concentrations of these ions can also be indicative of changes in the residence time or source of spring water.

Nutrients (Total N and Total P) are essential for life. In aquatic systems, the limiting macronutrient is often N, P, or both (Elser et al. 2009). These constituents can be found in springs due to either their presence in the aquifer feeding the spring or to surface input at the spring site. Monitoring Total N and Total P will determine whether changes at the surface, including recreational use, are affecting water quality. Hendrickson et al. (2008) compared water quality data collected in 1983 and 1999-2001 from 10 springs in the Cuatro Cienegas National Protected Area, Mexico, and found that N and P concentrations exhibited the greatest changes.

Response Design: A sample will be collected and submitted for laboratory analysis of water chemistry every other year at each selected large spring, at the same time that the BMI sample is collected. These samples will be collected in late February or early March in the southern desert parks (DEVA, MOJA, LAKE, JOTR, and PARA) and in late May or early June in GRBA. The chemistry of spring water is relatively steady, and water quality tends to change less slowly than discharge (Hendrickson et al. 2008), so this frequency should be sufficient to detect long-term trends.

Any large, rapid changes in water chemistry are likely to be detected by the quarterly water quality measurements.

2.2.4. Benthic Macroinvertebrates

Rationale: Benthic macroinvertebrates (BMI) are an abundant, diverse, and ecologically important component of many aquatic biological communities. Macroinvertebrates are also widely used to infer water quality stability in streams because macroinvertebrate assemblages are sensitive to changing physical, chemical, and biological conditions over multiple spatial and temporal scales (Barbour et al. 1999, Karr and Chu 1999). The link between water quality and BMI communities in springs is much less well studied, and no widely-accepted metrics have been established, although Sada et al. (2005) found changes in community structure associated with habitat degradation in the springs in the Spring Mountains of Nevada. In addition to the potential link to water quality, the purpose of the BMI monitoring is twofold:

- to provide data regarding the overall health of the aquatic ecosystems in the monitored springs, and
- to monitor the endemic species present in the springs.

These data will be useful in determining the effects of any observed changes in hydrology or vegetation, and will provide baseline information that can be used to evaluate management actions at the springs.

Response Design: A BMI sample will be collected every other year at each selected large spring, at the same time that the water chemistry sample is collected (February or March in the southern desert parks and late May or early June in GRBA, with each spring visited during the same two-week index period each biennium). For the reasons noted above, this frequency should be sufficient to detect long-term changes in BMI community structure. A biennial sampling frequency also significantly reduces the cost of the monitoring effort.

We anticipate several of the smaller springs have BMI communities that are taxon-poor, lack species that are sensitive to environmental variation, and are composed of species adapted to ephemeral habitats and harsh environmental conditions. Consequently, the BMI communities may not be well-suited to detecting environmental change because composition of the communities of small springs are often dominated by stochastic colonization processes (e.g., Bogan and Lytle 2011) rather than responses to local environmental conditions. After one or two BMI samples have been collected from each spring, we will determine whether BMI communities have sufficient taxon-richness to justify the costs of sample collection and processing on a spring-by-spring basis.

There are two springs where BMI samples will not be collected: Rogers Spring at LAKE and MC Spring at MOJA. Rogers Spring has been highly altered to create a bathing pool, and its aquatic ecology is dominated by aquarium fish and turtles released by park visitors. MC Spring is the sole natural habitat for the Mohave Tui Chub, an endemic fish species. BMI samples will not be collected from MC Spring to avoid disturbing the chub habitat.

2.2.5. Springsnails

Rationale: Springsnails (*Tryonia* and *Pyrgulopsis* spp.) are being monitored because they are a relatively long-lived sessile aquatic species. As a result, they are exposed to water of the same reach of springbrook for an extended period of time. Many springsnails in the region are adapted to such uniform water quality that they cannot survive in water from even very similar springs (D. Sada, personal communication). Therefore, it is expected that small changes in water quality would result in measureable changes to their population density. In addition to their value as an indicator of water quality, springsnails are of interest because they have limited distributions and may be endemic to individual spring complexes, and they have been extirpated from many springs in the region. Consequently, the monitoring of springsnail populations is a priority for park managers.

Response Design: Springsnail monitoring will be carried out every other year at each selected large spring that hosts a springsnail population (Blue Point Spring in LAKE, all five monitored springs in DEVA, and Tassi Spring in PARA). The springsnail monitoring will be carried out at the same time that the water chemistry and BMI samples are collected. For the reasons noted above, this frequency should be sufficient to detect long-term changes in springsnail population. A long-term springsnail monitoring program in the Spring Mountains of Nevada began with annual sampling, but reduced the frequency due to the lack of observed change (D. Sada personal communication). A biennial sampling frequency also significantly reduces the cost of the monitoring effort.

2.2.6. Monitoring Wells

Rationale: A spring's discharge may change in response to changes in the near surface environment (e.g., changes in vegetation, increased air temperature, changes in near-surface flowpaths) or to changes in the water level in the source aquifer. Collecting water level data from monitoring wells in aquifers near the spring will help to distinguish between these two effects. If a spring's flow is impacted by groundwater withdrawal, then a decline in aquifer water level would be a key line of evidence in establishing cause and effect. Therefore, monitoring water levels in source aquifers is a high priority for park managers.

Response Design: No new monitoring wells will be constructed specifically for this protocol. Instead, data will be collected at existing wells that are located within park boundaries. While the use of these wells constitutes a judgment sampling plan, the high cost of well drilling precludes any other approach.

The only two wells that meet this criterion and are not being monitored by another entity are the Rogers Bay well in LAKE and the Baker Creek Road well in GRBA. The DEVA hydrology staff work with the NPS WRD to monitor a network of 29 monitoring wells. If this arrangement becomes unsustainable in the future, some or all of these wells may be added to the SLS protocol monitoring.

In general, the water level in each well will be monitored with either an electronic tape (for water levels less than 50 feet [15.2 meters] below ground surface) or a steel tape (for water levels more than 100 feet [30.5 meters] below ground surface) using measuring points established during previous monitoring. When MOJN I&M begins monitoring wells that have been monitored by other agencies, care will be taken to ensure comparability between the data sets.

2.3. Power Analyses

A power analysis is a tool for assessing the value of a given monitoring before implementing it (e.g., Sims et al 2006). Monte Carlo simulations are used to determine how quickly a given monitoring plan will be able to detect statistically-significant changes in the monitored parameter. A comparison of the statistical power to detect changes can then be used in the cost-benefit analysis involved in selecting a monitoring plan.

L. A. Starcevich conducted power analyses using historical discharge data from two springs in LAKE (Blue Point Spring and Rogers Spring) and one spring in MOJA (Piute Spring), and historical water chemistry data from one spring in DEVA (Saratoga Spring). These springs were selected based on the availability of historical data.. It has been previously shown that statistically-significant trends can be detected in water level data collected in wells near DEVA (Fenelon and Moreo 2002), so no analyses of historical well data were carried out. Insufficient historical data were available for power analyses of BMI community structure or springsnail population.

2.3.1. Discharge Power Analyses

Power analyses were performed on USGS discharge records for Blue Point Spring and Rogers Spring in LAKE and mining company discharge records for Piute Spring in MOJA (Figure 28), which is not included in the SLS protocol. Piute Spring was analyzed because it has a multi-year record that exhibits more seasonal and inter-annual variation in discharge than the records from the two LAKE springs, and may therefore be more representative of some of the more variable springs included in the protocol. The pilot data for these springs spans 11, 26, and 8 years, respectively (Table 12). The Blue Point Spring and Rogers Spring records contain daily data, while the Piute Spring data was collected on a monthly basis for two years and on a quarterly basis for the remainder of the record. The Blue Point Spring, Rogers Spring, and Piute Spring discharge records are graphed in Figures 17, 19, and 28, respectively. As described in Section 1.3.4, there are changes in the character of the discharge record for Rogers Spring due to the installation of a flume. However, we have chosen to perform power analyses on the imperfect record because:

1. similar problems are not uncommon in multi-decade monitoring records, so the problems in the Rogers Spring may be encountered in data that is collected in this protocol, and,
2. the changes in gaging method increase the variation within the record, making it more likely that our power analysis will understate our ability to detect changes than that they will overstate it.

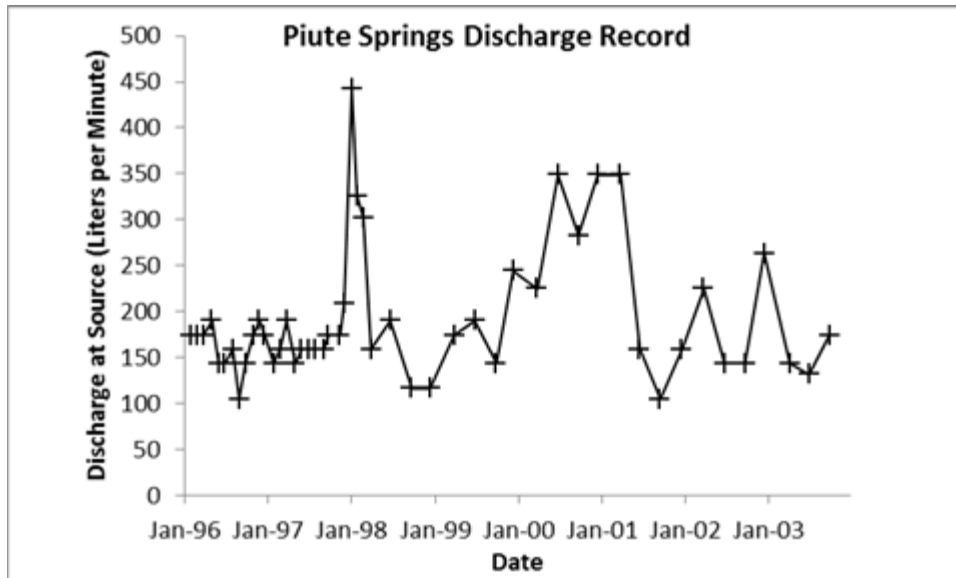


Figure 28. Discharge data for Piute Spring in MOJA collected by Viceroy Gold Corporation.

Table 12. Date ranges for discharge records used in power analyses.

Spring	Date Range
Blue Point	October 1999 through October 2009
Rogers	August 1985 through July 2010
Piute	January 1996 through September 2003

The pilot data trend analysis was conducted with an amended mixed model proposed in VanLeeuwen et al. (1996) and Piepho and Ogutu (2002). Mixed models include fixed effects, which contribute to the mean of the outcome of interest, and random effects, which contribute to the variance. Random effects are used to estimate variation of linear trends among sites and over time. In our application, trends are measured independently for each spring, so site-level random effects for intercept and slope are not incorporated into the trend model.

Initial data analysis indicated strong temporal correlation among daily discharge measurements, but not amongst monthly measurements. To determine the appropriate sampling interval, subsets of the data were examined. Monthly sampling was examined by using data from the first day of each month. Quarterly sampling included data from March 1, June 1, September 1, and December 1 of each year. The annual sampling revisit design was examined by taking the data from June 1 of each year. These revisit designs were exactly followed for Blue Point and Rogers Springs. The revisit designs were applied as closely as possible to less-frequently sampled Piute Spring data.

The natural logarithmic transformation was applied to the discharge measurements because the transformation did not adversely affect the model fit and allows for convenient interpretation of multiplicative change over time. When appropriate, seasonal and monthly effects and their interactions were examined. Model selection was conducted by comparing corrected Akaike

Information Criterion (AICc) and Bayes Information Criterion (BIC) values (Gurka 2006) and by evaluating residuals to ensure homoscedasticity and normal distribution.

The mixed linear model used for stream discharge monitoring outcomes in each of the three pilot data sets is:

$$\log(y_{ij}) = \beta_0 + w_j\beta_1 + b_j + e_{ij},$$

where $i=1,...,12$; $j=1,...,m_b$; and

m_b = the number of consecutive years in the sample;

w_j = constant representing the j^{th} year (covariate);

β_0 = fixed intercept;

β_1 = fixed effect coefficient of the linear time trend;

b_j = random intercept of j^{th} spring, i.i.d. $N(0, \sigma_b^2)$;

e_{ij} = unexplained error, i.i.d. $N(0, \sigma_e^2)$.

For each pilot data set and revisit design, the model that performed best (judged from AICc/BIC values and residual diagnostics) contained only an intercept and linear year term. Random year effects were incorporated for the monthly and quarterly designs. The annual revisit design did not provide enough replication to estimate random year effects, so the trend model reduced to simple linear regression in this case. Residual analysis indicated that the simple linear regression fit to the annual sampling data may not be the most appropriate fit. However, other transformations and higher-order year terms did not improve the fit.

Power is assessed by simulation. The populations are generated 1000 times using the fixed intercept and random effects variance components, and then the population is simulated to decline over time at a known rate. For time intervals of 5, 10, 15, 20, 25, and 30 years, the power to detect a significant trend in a hypothesis test of no trend against a one-sided alternative hypothesis of a decreasing trend is assessed as the proportion of times the null hypothesis is rejected at the Type I error rate of 0.10.

The power results are plotted for each of the three springs for each revisit design (Figures 29 to 31) and provided in Tables 13 to 15 for monthly, quarterly, and annual revisit designs, respectively. The power simulations indicate that annual declines of 5% may be detected with power of 0.8 in 10 to 15 years for monthly or quarterly discharge measurements from Blue Point and Rogers Springs. Power to detect a 5% annual decline in Piute Spring discharge is considerably lower, requiring 20 to 25 years to detect trends with power of 0.8 when monthly or quarterly revisits are used. For the annual revisit design, power to detect a 5% annual decline in discharge is slightly lower for monitoring periods of 10 years or less. However, for longer monitoring periods, the power to detect a 5% annual decline in Piute Spring discharge is higher for the annual revisit design than for the monthly or quarterly revisit designs. It is likely that this discrepancy would be eliminated if a longer record were available.

Overall, the discharge power analyses show that quarterly monitoring will provide sufficient statistical power to detect declines in discharge, and that increasing the monitoring frequency to monthly would not greatly increase that power.

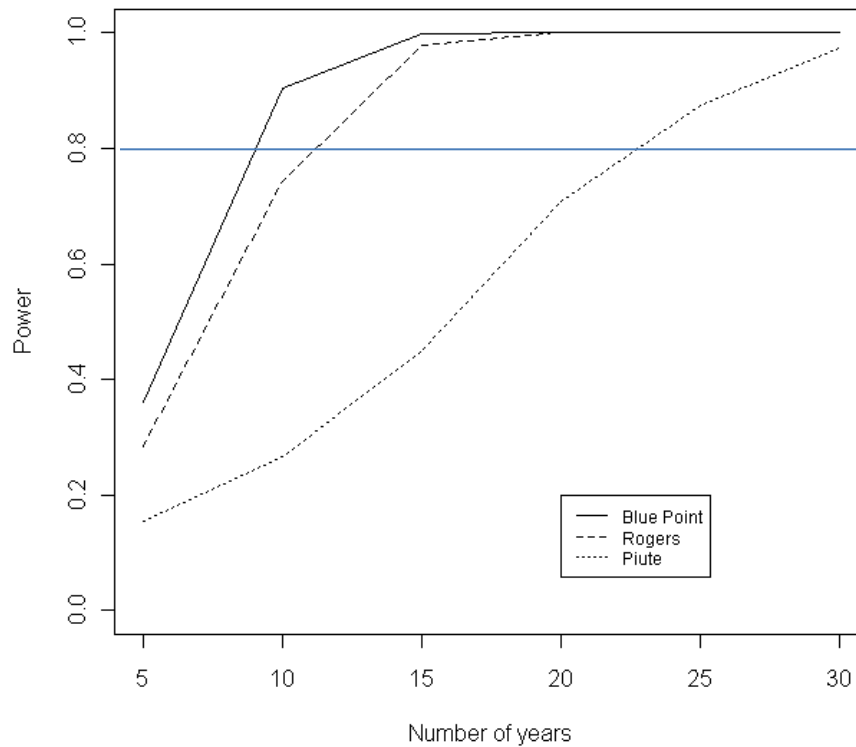


Figure 29. Simulation power for trend testing of annual declines in discharge of 5% per year for three springs with monthly sampling.

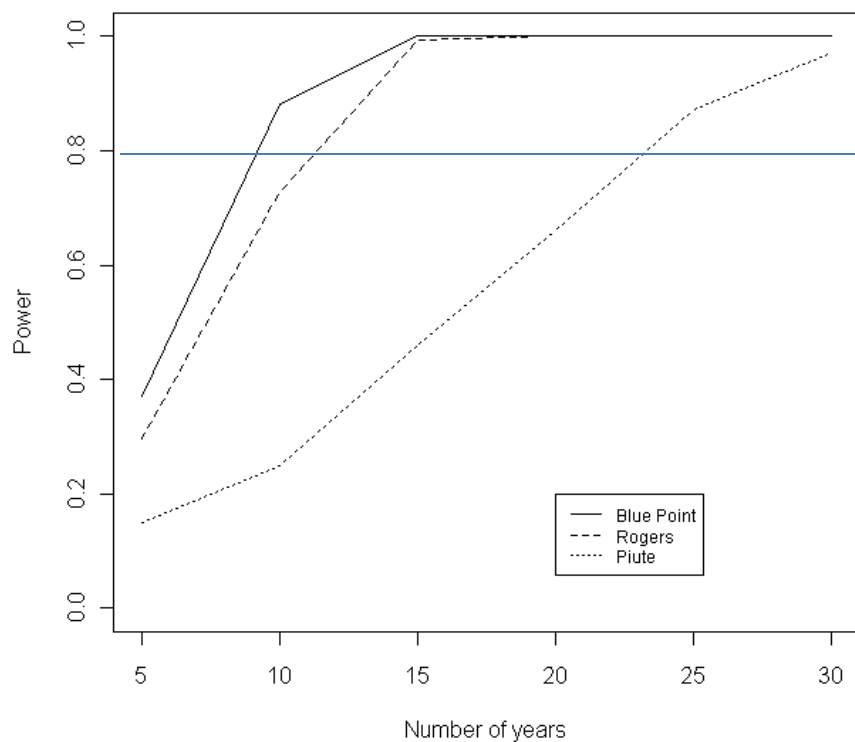


Figure 30. Simulation power for trend testing of annual declines in discharge of 5% per year for three springs with quarterly sampling.

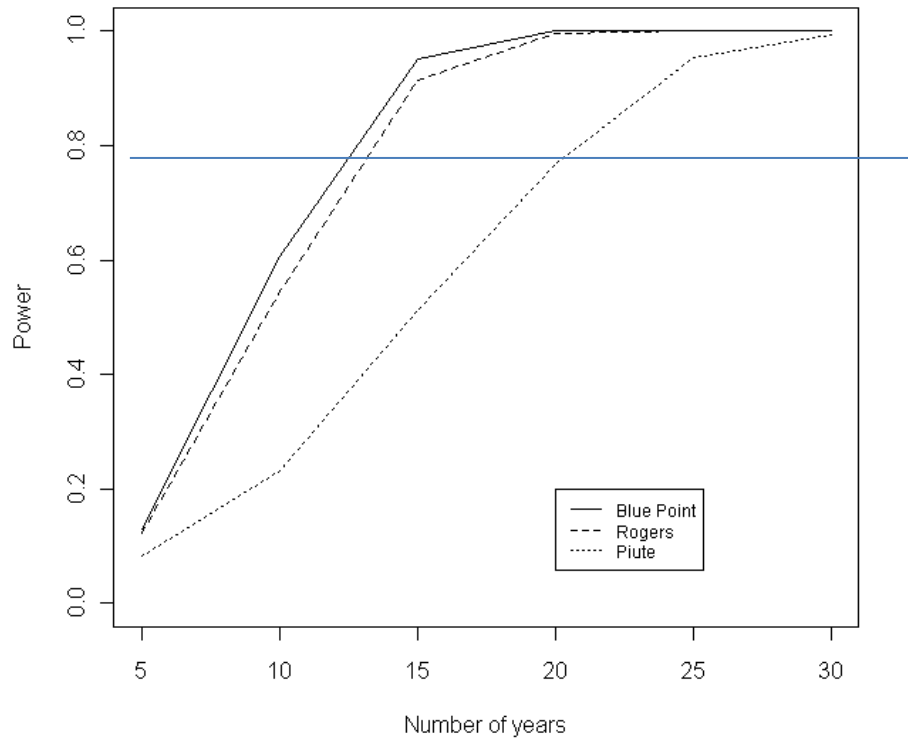


Figure 31. Simulation power for trend testing of annual declines in discharge of 5% per year for three springs with annual sampling.

Table 13. Power to detect an annual decline of 5% in spring discharge with monthly sampling.

Number of Years	Blue Point Spring	Rogers Spring	Piute Spring
5	0.361	0.283	0.154
10	0.905	0.743	0.266
15	0.998	0.979	0.449
20	1.000	1.000	0.708
25	1.000	1.000	0.874
30	1.000	1.000	0.973

Table 14. Power to detect an annual decline of 5% in spring discharge with quarterly sampling.

Number of Years	Blue Point Spring	Rogers Spring	Piute Spring
5	0.370	0.297	0.151
10	0.883	0.728	0.249
15	1.000	0.993	0.459
20	1.000	1.000	0.660
25	1.000	1.000	0.873
30	1.000	1.000	0.970

Table 15. Power to detect an annual decline of 5% in spring discharge with annual sampling.

Number of Years	Blue Point Spring	Rogers Spring	Piute Spring
5	0.130	0.122	0.082
10	0.607	0.544	0.232
15	0.952	0.913	0.511
20	1.000	0.997	0.768
25	1.000	1.000	0.954
30	1.000	1.000	0.993

2.3.2. Water Chemistry Power Analyses

Power analyses were performed using the historical observations of Ca, Mg, Na, SO₄, and HCO₃ in Saratoga Spring presented in Table 3. The natural logarithm transformation was used for these five analytes because the residuals better met assumptions for model fitting and the transformation allows for convenient interpretation of the multiplicative change. Mixed models yielded non-zero estimates of year-to-year variation for all outcomes except Mg and HCO₃, but produced errors indicating over-parameterization for these outcomes in the simulation. Therefore, simple linear regression of the logged outcome was used for trend testing in the power simulation. Biennial sampling was simulated for the power analyses.

A Monte Carlo power simulation incorporated estimates of the baseline mean and residual error obtained from historic data to simulate similar populations exhibiting known change. Power is approximated as the proportion of iterations for which the null hypothesis is accurately rejected in favor of the two-sided alternative hypothesis of no trend. Simulation runs for no trend over time indicated that this approach exhibits stable trend test size. The results of the power simulation are provided for annual declines of 1% (Table 16) and 5% (Table 17). The results indicate that even relatively small trends may be detected with at least 0.8 power for most of these analytes within 5 to 15 years. Detecting trends in Mg over time provided the lowest power, requiring more than 30 years to detect an annual 1% decline and about 12 years to detect a 5% decline with power of 0.8.

Table 16. Power of biennial sampling to detect a 1% annual decline with simple linear regression.

Number of Years	Ca	Mg	Na	SO ₄	HCO ₃
5	0.143	0.088	0.399	0.857	0.293
10	0.626	0.128	0.998	1.000	0.956
15	0.981	0.213	1.000	1.000	1.000
20	1.000	0.334	1.000	1.000	1.000
25	1.000	0.543	1.000	1.000	1.000
30	1.000	0.756	1.000	1.000	1.000

Table 17. Power of biennial sampling to detect a 5% annual decline with simple linear regression.

Number of Years	Ca	Mg	Na	SO ₄	HCO ₃
5	0.877	0.159	1.000	1.000	0.999
10	1.000	0.684	1.000	1.000	1.000
15	1.000	0.991	1.000	1.000	1.000
20	1.000	1.000	1.000	1.000	1.000
25	1.000	1.000	1.000	1.000	1.000
30	1.000	1.000	1.000	1.000	1.000

2.4. Other Sample Design Approaches Considered

Two additional approaches were strongly considered during the sample design process: the collection of continuous discharge data at all springs and the collection of continuous well level data.

The decision to collect continuous discharge data at some springs but not others was driven by logistics: some of the springs are in steep washes where any flumes and monitoring equipment would be unlikely to survive major storms, while others are in areas of cultural importance where no equipment could be installed.

The decision not to continuously monitor wells was made based on the additional resources that would be required: the data management team would be required to develop an additional database to store a large amount of data, and the Protocol Lead and Data Manager would be required to process

and manage approximately 20 additional data sets per quarter. In addition, a USGS study (Fenelon and Moreo 2002) found that statistically significant trends could be identified in water level in wells in the region using periodically-collected data.

Because continuous spring discharge data and water level data would directly address the monitoring questions for this protocol, the decision not to collect these data continuously will be reviewed two years after protocol implementation, prior to the quadrennial protocol review (Section 5.6). At that time, the Protocol Lead will determine whether the data from the quarterly-monitored springs show similar patterns to the continuously monitored springs, or if they exhibit a separate trend or seasonal pattern. They will also determine whether the well level data remain relatively unchanged throughout the year or exhibit variations that cannot be understood without higher-frequency monitoring.

3. Field and Laboratory Methods

3.1. Standard Operating Procedures

The Standard Operating Procedures included in a companion volume to this narrative describe field collection methods in detail, including logistics, field sampling methods, QA/QC, and data analysis and reporting procedures (Table 18). In general, SOPs are organized by field activity and sampling trip. For example, field sampling for water chemistry and BMIs are combined into one SOP.

Table 18. Standard Operating Procedures (SOPs).

Title	Description
SOP 1: Safety	Provides safety information, checklists, and forms with personnel who are involved with field activities and covers general safety issues associated with field sampling and back-country travel
SOP 2: Staff Training	Describes the training requirements for the Springs Protocol
SOP 3: Spring Locations and Spring-Specific Procedures	Gives directions to each spring and describes how the SOPs will be implemented at each location.
SOP 4: Field Mobilization and De-Mobilization	Covers trip preparations and the cleaning, inventorying, and storage of equipment
SOP 5: Equipment Disinfection	- Describes the procedure for disinfecting field equipment that contacts water or organisms - The purpose is to prevent the introduction and spread of non-native organisms to other water bodies
SOP 6: Handheld Water Quality Instrument	Describes the collection of discrete measurements of the four core water quality parameters using a handheld multiprobe
SOP 7: Spring Discharge Monitoring	- Describes the methods for estimating stream discharge measurements - Includes field procedures for sites with permanent flumes and water level loggers, sites where discharge is measured with a portable flume, and sites where discharge is measured volumetrically
SOP 8: Water Sampling, BMI Sampling, and Springsnail Monitoring	Describes the procedures for co-collection of water and benthic macroinvertebrate samples and springsnail population monitoring
SOP 9: Monitoring Water Levels in Wells	Describes the procedures for measuring water levels in monitoring wells
SOP 10: Sample Handling	Describes how the three types of samples (water, BMI, and springsnail) collected under the Selected Large Springs protocol should be handled, stored, and shipped
SOP 11: Laboratory Analysis of BMI	Describes the procedures for enumeration and identification of benthic macroinvertebrates by a qualified taxonomy laboratory
SOP 12: Laboratory Analysis of Water Chemistry	Describes the procedures for storing, handling, and shipping samples to a qualified laboratory for analysis. It also includes criteria for selecting laboratories including minimum MDLs
SOP 13: Quality Assurance Project Plan (QAPP)	Describes quality assurance and quality control objectives and procedures related to data collection
SOP 14: Cumulative Measurement Bias	Describes the steps the network will take to avoid cumulative measurement bias

Table 18. Standard Operating Procedures (SOPs) (continued).

Title	Description
SOP 15: Data Analysis and Reporting	Describes reporting requirements and details of data analysis, including statistical analyses
SOP 16: Data Management	Describes the protocol information workflow, database design, and other data management concerns.
SOP 17: Protocol Revision and Review	Describes how protocol revisions should be recorded, provides a location for future changes to be noted.

3.2. Logistics

3.2.1. Permitting

NPS research permits are required for monitoring activities. After these permits have been granted, Investigator Annual Reports (IARs) are due every year prior to March 31. It is crucial to the protocol that the proper channels be followed in dealing with these permits. As of 2014, permit applications and IARs can be submitted online at: irma.nps.gov/rprs.

For the Selected Large Springs protocol, an important issue in permit compliance will be handling the BMI samples correctly. These samples will remain the property of the parks in which they were collected, but they will go onto long term loan to the Utah State University BugLab in Logan, Utah, after processing. Archived samples are crucial to long term BMI monitoring efforts, as taxonomic identification can drift over time. The Protocol Lead will work with the curation staff member at each park to ensure that MOJN I&M remains in compliance with the park's requirements.

3.2.2. Safety

Many of the selected large springs are in isolated locations, so the primary safety issues are related to travel in remote areas. Park radios should be used whenever possible, and both park and MOJN I&M personnel should be aware of when field work is being carried out and when field personnel are expected to return. A full description of safety procedures and a sample Job Hazard Analysis (JHA) are included in *SOP 1: Safety*.

3.2.3. Site Access

The monitored springs will be accessed by driving and hiking. Most of the monitored springs are less than a kilometer from the nearest road. Staff will be trained in back-country driving prior to monitoring locations accessed via unpaved roads. Directions to each site are given in *SOP 3: Spring Locations and Spring-Specific Procedures*.

3.3. Field Methods

The variety of spring types covered by the Selected Large Springs protocol can require the use of varying field methods between springs. Table 19 summarizes the field methods used at each spring (water quality and water chemistry methods do not vary between springs, and so are not included). The methods are summarized in the following sections and discussed in detail in the SOPs.

Table 19. Summary of field methods applied to selected large springs. Water quality data and chemistry samples are collected with the same methods at all springs.

Park	Quarterly Well Monitoring	Spring	Discharge Measurement Method	Discharge Measurement Frequency	Number of Biennial BMI Samples	Biennial Springsnail Monitoring
DEVA	none	Saratoga	pool stage ¹	continuous	3	yes
		Texas	flume ¹	continuous	1	yes
		Travertine	flume, flowmeter ¹	continuous	2	yes
		Nevares	flume, flowmeter ¹	continuous	2	yes
		Mound	flume ¹	continuous	To be determined	yes
JOTR	none	49 Palms	pool area	quarterly	1	no
		Smith Water Canyon	springbrook length	quarterly	1	no
LAKE	Rogers Bay well	Blue Point	weir	continuous	2	yes
		Rogers	flume ²	continuous	0	no
MOJA	none	MC	pool stage	continuous	0	no
GRBA	Baker Creek Road well	Boiler	stream gaging	twice a year	1	no
		Strawberry Source	stream gaging	twice a year	1	no
		Marmot	volumetric	Three times a year	1	no
PARA	none	Pakoon	To be determined	continuous	2	no
		Tassi	Volumetric or portable flume	quarterly	1	yes

¹ Measurements made by DEVA staff, data analyzed by WRD.

² Measurements and data analysis by USGS.

3.3.1. Discharge

As Table 19, shows, several different methods are used to measure discharge at the selected large springs. The rationale for the choice of discharge methods for each spring is given in Section 2.2.1.

The discharges of the five SLS protocol springs in DEVA are jointly monitored by the park staff and WRD. The discharge of Rogers Spring at LAKE is monitored by the USGS. MOJN I&M will not be involved in discharge monitoring at these springs as long as these arrangements persists.

The total open water area at Fortynine Palms Oasis in JOTR will be estimated using the method described by the Nova Scotia Environment Vernal Pool Mapping and Monitoring Project (<http://www.novascotia.ca/nse/wetland/vernal.pool.mapping.project.asp>; accessed 12 September 2014). At each pool, the maximum length and width are measured. The pool is then drawn to scale on graph paper, with additional measurements made as needed to ensure that the total area is accurate to within 10%.

The springbrook length at each outlet of Smith Water Canyon Springs in JOTR will be measured by stretching a measuring tape along the channel from the source to the furthest extent of the surface water.

Blue Point Spring will be gaged using the permanent weir used by the USGS from 1999 to 2012. A pressure transducer has been installed in a stilling well in the weir pool. At each quarterly visit, stage data will be downloaded from the pressure transducer and the staff gage will be read. In accordance with USGS practice at the site, the stage readings will be converted to discharge using the standard equation for a V-notch weir.

Pool stage will be monitored at MC Spring using a pressure transducer and a staff gage. At each quarterly visit, stage data will be downloaded from the pressure transducer and the staff gage will be read.

Boiler Spring and Strawberry Source Spring at GRBA will be gaged using standard USGS gaging methods for streams to ensure comparability with data collected as part of the MOJN I&M Streams and Lakes Monitoring protocol and to preserve the natural character of the channels. The SOP for this work is *SOP 7: Stream Discharge Monitoring* (Moret et al. 2012). A copy of the SOP is included in the Supplemental Materials for this protocol. The MOJN I&M Streams and Lakes Protocol Lead should be consulted to obtain a copy of the most up-to-date version of the SOP. These springs will be monitored twice a year, in late June and late August or early September.

Volumetric discharge measurements (described by Turnipseed and Sauer (2010) as “the most accurate method of measuring small discharges”) will be used to monitor the discharge of Marmot Spring. The flow from the culvert below Baker Creek Road will be captured in container of known volume, and the time required to fill the container will be recorded. This process will be repeated seven times each visit.

The discharge from Tassi Spring will be measured each quarter using the volumetric method or a portable flume or weir plate. The decision on which method to use will be made after several quarters of trial monitoring. Volumetric measurements are described above. If a portable flume or weir plate is used, then care will be taken to ensure that the spring’s entire flow is channeled through the control structure, and that it is properly leveled. The staff gage will be read three times to minimize errors. Stage readings will be converted to discharge using the standard equation for the control structure.

3.3.2. Water Quality

Water quality will be measured using standard handheld multiprobe instruments such as MOJN I&M’s YSI 556. Park staff will collect data with park-owned instruments. Data inconsistencies and cumulative bias will be avoided by:

1. Calibrating all instruments at the WRD-recommended intervals
2. Using the same instruments for each spring to the extent possible
3. Recording the instrument used for each measurement

4. Performing annual Alternative Measurement Sensitivity Plus (AMS+) checks of precision for each instrument.

The four core parameters (pH, temperature, DO, and specific conductance) must be collected at each site. The instrument measures electrical conductivity, and uses a temperature correction algorithm to collect specific conductance. Because these algorithms may vary between instruments, the raw electrical conductivity must be reported as well.

In springs where the source is contained within a springbox, measurements should be collected in the springbox. Three measurements should be taken in the field to prevent the inclusion of outlier data. In rheocrene springs without springboxes, three measurements should be made across the springbrook at 25%, 50%, and 75% of the wetted width. The measurements should be made at mid-water column depth. All parameters should be recorded for each measurement.

In limnocrene springs without springboxes or springbrooks, depth profiles of core parameters should be collected. The total depth of the pool should be measured, and measurements made near the surface, at 1/3 of the total depth, at 2/3 of the total depth, and near the bottom.

3.3.3. Water Chemistry

Water samples will be collected as near the source as possible using the hand-dipping method. The testing laboratory should be consulted for the amount and type (filtered or unfiltered) of sample required. At this time, it is anticipated that one 1 L bottle of unfiltered sample should be collected. Latex or other clean, disposable, waterproof gloves will be worn to minimize contamination.

3.3.4. Benthic Macroinvertebrates

Sampling benthic macroinvertebrates is challenging in springs and requires varying methods that are suitable for the various spring types and microhabitats present within springs. Because there are no standard methods for BMI sampling in springs that are appropriate for long term monitoring, we have developed methods loosely based on the EMAP protocols for BMI collection in streams (Peck et al. 2006) and the methods developed by the National Aquatic Monitoring Center (NAMC) for the Western Lake Survey Project (NAMC 2006). After one or two rounds of samples have been collected from each spring, we will determine whether BMI communities have sufficient taxon-richness to justify the costs of sample collection and processing on a spring-by-spring basis.

BMI samples will be collected biennially in all of the monitored springs except Rogers Spring and MC Spring. Rogers Spring is highly disturbed and heavily used for recreation, while MC Spring is very small and the only remaining natural habitat of the Mohave Tui Chub. The sampling method for the remaining springs is outlined in Table 20.

Table 20. BMI sampling overview for selected large springs.

Park	Spring	Sample Name	Method
DEVA	Travertine	Travertine No. 1 Source	channel
		Travertine No. 1 Downstream	channel
		Travertine No. 2 Reachwide	channel
	Nevares	Nevares Source	channel
		Nevares Downstream	channel
	Texas	Texas Source	channel
	Saratoga	Saratoga Source	pool
		Saratoga Channel	channel
		Saratoga Ponds	pool
	Mound	TBD	TBD
GRBA	Strawberry Source	Strawberry Source	channel
	Boiler	Boiler	channel
	Marmot	Marmot	channel
JOTR	Fortynine Palms	Fortynine Palms	multi-pool grab
	Smith Water	Smith Water	multi-pool grab
LAKE	Blue Point	Blue Point Source	channel
		Blue Point Downstream	channel
PARA	Pakoon	TBD	TBD
	Tassi	Tassi	channel

Channel Method: For springs with distinct springbrooks, the channel method (based on Peck et al. 2006) will be used. Sampling locations will be established on the left, center, or right of the springbrook at regular intervals along the sampling reach. At each location, a net with a 500 µm mesh will be placed on the streambed, and quadrat of a defined size upstream of the net will be disturbed for 30 seconds, causing all of the benthic macroinvertebrates in the quadrat to be swept into the net. The net size, quadrat size, sampling reach, and sampling location interval for each spring are defined in *SOP 3: Spring Locations and Spring-Specific Procedures*. The samples from each location will be composited into a single sample for submittal to the taxonomic laboratory.

Pool Method: In pools, the monitoring method is based on the methods developed by the NAMC for the Western Lake Survey Project (NAMC 2006). Samples will be collected at ten evenly-spaced locations around the spring pool using a D-net with a 500 µm mesh and combined into a single composite sample.

Multi-Pool Grab Sample: The two SLS protocol springs at JOTR consist of a number of small pools. At these springs, BMI samples will be collected from three 12 cm x 12 cm quadrats in each pool, with all samples from all pools combined into a single spring-wide sample.

3.3.5. Springsnails

The springsnail monitoring method is based on the work of Sada (2009). The monitoring will occur biennially at those springs with springsnail populations. The furthest downstream extent of the

spring snail population will be located, and its GPS coordinates will be recorded. A tape will be stretched from the source to this downstream extent, and monitoring locations will be established at a number of equally-spaced points between the source and the extent. At each location, the spring snails within a quadrat placed on the left, center, or right of the channel bottom will be sieved from the substrate and counted, providing estimates of spring snail population density. The net size, quadrat size, sampling reach, and sampling location interval for each spring are defined in *SOP 3: Spring Locations and Spring-Specific Procedures*. At some springs, the quadrats will be located adjacent to the BMI sampling quadrats.

3.3.6. Well Monitoring

Water levels in monitoring wells will be measured using a steel tape (for water levels deeper than 50 feet [15.2 meters]) or an electronic water level tape (for water levels shallower than 50 feet [15.2 meters]). All measurements will be made from either the marked measuring point or from the north side of the casing.

Steel tape measurements will be made following USGS Ground Water Technical Procedure Document 1 (GWPD-1, Cunningham and Schalk 2011). The bottom portion of the tape will be marked with chalk, and the tape will be unspooled until the chalked portion is partly under water. The tape will be read at the measuring point (the “hold” reading), then it will be spooled in until the chalked portion reaches the surface, when the length of the wetted portion of the tape (the “cut” reading) will be recorded. The difference between these two readings is the depth to water. Readings will be recorded to the nearest 0.01 feet (0.30 centimeters). The process should be repeated at least once as a precision check.

Electric tape measurements will be made following USGS GWPD-4 (Cunningham and Schalk 2011). The tape will be unspooled into the well until the buzzer sounds, and the depth-to-water will be recorded at the exact point where the buzzer begins to sound. Readings will be recorded to the nearest 0.01 feet (0.30 centimeters). Once the reading has been recorded, the tape will be reeled in, and two additional duplicate measurements will be made. All three measurements will be recorded.

3.4. Laboratory Methods

3.4.1. BMI Laboratory Methods

Identification of macroinvertebrates will be conducted by the National Aquatic Monitoring Center, also known as the USU BugLab. The USU BugLab is a cooperative venture between Utah State University and the U.S. Bureau of Land Management. The sampling protocol currently specifies that the entire sample is enumerated and 600 randomly subsampled individuals are identified to lowest taxonomic level (genus for most insects). Identification to genus will be conducted for the Chironomidae, an important dipteran family with high species richness. The SOP includes detailed laboratory procedures, including subsampling methods and QA/QC criteria used by the taxonomy laboratory. *SOP 15: Data Analysis and Reporting* includes details on the indices to be calculated.

3.4.2. Water Chemistry Laboratory Methods

Water samples collected as part of the Selected Large Springs protocol will be submitted to a laboratory that is certified by Nevada Department of Environmental Protection's Bureau of Water Quality Planning to perform analyses for projects related to the Safe Drinking Water Act, the Clean Water Act, and/or the Resource Conservation and Recovery Act (Nevada does not participate in the NELAP program). Samples will be analyzed using the methods and measurement quality objectives (MQOs) presented in Table 21.

Table 21. Analytical methods and measurement quality objectives (MQOs) for parameters measured in the laboratory.

Parameter	Method	Precision MQO	Bias MQOs		Sensitivity MQOs	
		Relative percent difference (RPD of duplicates) ¹	Blanks (field)	Measurement systematic error (% recovery) ²	Method detection limit (MDL) ³	Laboratory-defined reporting limit (RL) ⁴
Alkalinity (mg/L as HCO ₃ ⁻)	Standard Method (SM) 2320 B	+/-30%	<MDL	90–110%	0.01	20
Chloride (mg/L)	SM 4500-Cl B	+/-30%	<MDL	90–110%	5	10
Sulfate (mg/L)	EPA Method 375.4	+/-30%	<MDL	90–110%	0.1	10
Calcium (mg/L)	SM 3111 B	+/-30%	<MDL	90–110%	0.7	10
Sodium (mg/L)	SM 3111 B	+/-30%	<MDL	90–110%	2	10
Potassium (mg/L)	SM 3111 B	+/-30%	<MDL	90–110%	0.04	0.25
Magnesium (mg/L)	SM 3111 B	+/-30%	<MDL	90–110%	0.01	1
Total nitrogen (mg/L)	SM 4500-NH ₃ D, -NO ₃ E, -NO ₂ B	+/-30%		90–110%		1
Total phosphorus (mg/L)	Prep: SM 4500-P B(5) Analysis: SM 4500-P E	+/-30%	<MDL	90–110%	0.03	0.1

¹RPD is the relative percent difference between two or more measurements calculated as percent recovery:

$$RPD = \left[\frac{S_1 - S_2}{(S_1 + S_2)/2} \right] \times 100$$

where,

S₁ = the larger test result value,

S₂ = the smaller test result value.

²Measurement systematic error is set to 90–110% in the absence of any specific guidance for laboratory rejection criteria

³Defined by National Environmental Methods Index (NEMI) as the lowest "measurable" concentration for an analyte by the specified method (http://web1.er.usgs.gov/nemi/field_def.jsp?method_field_name=DL_VALUE).

⁴The RL is defined by the laboratory, and should never be less than the MDL multiplied by 3.18.

4. Data Management

The following section was adapted and modified from Starkey et al. 2008 and Heard et al. 2012. Many other NPS Network protocols were used for guidance.

This section outlines procedures for water quality and quantity and macroinvertebrate data handling, analysis, and report development. Additional details and context for this section may be found in the MOJN I&M Vital Signs Monitoring Plan (Chung-MacCoubrey et al. 2008), which provides an overview of the network's data management and reporting plan. The specific procedure and details concerning data management are only briefly discussed in this section. Details and procedural steps are documented in the SOPs with the assumption that as the protocol is implemented and adjusted through its lifecycle, the SOPs will be continually updated while the narrative of the protocol can remain largely unchanged. This is particularly necessary for data management due to rapid changes in technology and data management solutions.

All data and information are managed according to the specifications presented here and within the appropriate SOPs with one exception. Continuous discharge measures of selected large springs will follow the SOPs and data management procedures, including water quality reporting, as presented in the MOJN I&M Streams and Lakes protocol. Continuous discharge data from springs will be stored in the Streams database, reviewed for quality in the Streams database, and processed using Aquarius software in a manner identical to the Streams data. The Selected Large Springs master database will link to the springs data in the Streams master database. For additional details, please refer to the MOJN I&M Streams and Lakes protocol (Caudill et al. 2012).

4.1. Project Information Management Overview

Effective data management of network protocols requires a comprehensive project information management strategy that is detailed and structured within an annual cycle, designed for refinement as needed, and is sustainable throughout the lifecycle of the protocol (Figure 32). Primary responsibility for the project information management resides with the network Data Manager but is not effectively implemented without the assistance of network staff and cooperators. Detailed documentation of roles and responsibilities appears in MOJN I&M Data Management Plan (DM), MOJN-DM-SOP *Roles and Responsibilities* (Chung-MacCoubrey et al. 2008). A brief synopsis of each stage of the project management cycle follows (Siegel et al. 2007):

- *Preparation:* Training, logistics planning, print forms and maps
- *Data Acquisition:* Field trips to acquire data
- *Data Entry & Processing:* Data entry and uploads into the working copy of the database, GPS data processing, etc.
- *Quality Review:* Data are reviewed for quality and logical consistency
- *Metadata:* Documentation of the year's data collection and results of the quality review
- *Data Certification:* Data are certified as complete for the period of record

- *Data Delivery*: Certified data and metadata are delivered for archiving and uploaded to the master project database
- *Data Analysis*: Data are summarized and analyzed
- *Product Development*: Reports, maps, and other products are developed
- *Product Delivery*: Deliver reports and other products for posting and archive
- *Posting and Distribution*: Distribute products as planned and/or post to NPS clearinghouses
- *Archiving and Records Management*: Review analog and digital files for retention (or destruction) according to NPS Director's Order 19. Retained files are renamed and stored as needed
- *Season Closeout*: Review and document needed improvements to project procedures or infrastructure, complete administrative reports, and develop work plans for the coming season.

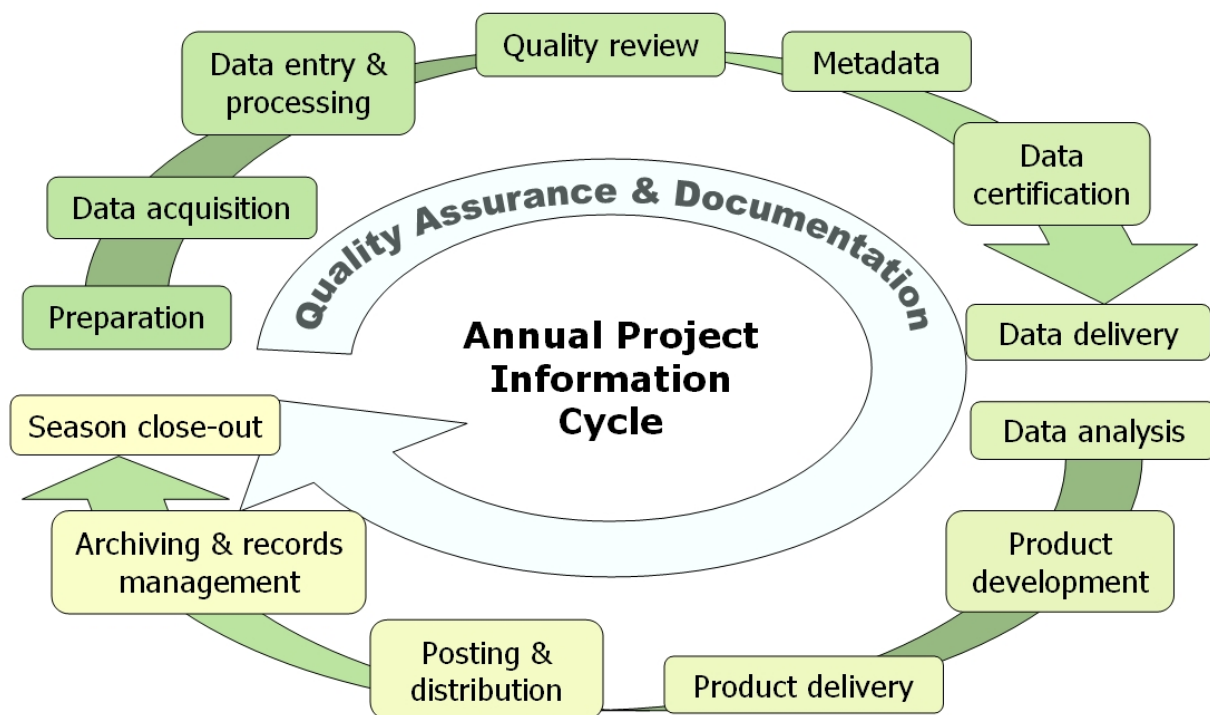


Figure 32. Scheme of managing project information on an annual cycle. Idealized flow schematic of the cyclical stages of project information management, from pre-season preparation to season close-out. *Note:* Quality assurance and documentation are thematic and not limited to any particular stage. Figure provided by NPS North Coast and Cascades Network, J. Boetsch, email communication, 2010.

Central to project information management is an information management workflow or road map, schedule of tasks, and mechanisms or tools to manage the data, i.e. software and databases, within the structure of the Project Information Management Cycle (Figure 32). *SOP 16: Data Management* presents an overall workflow of the data generated and managed for this protocol, and detailed individual steps associated with the workflow. A list of tasks and associated schedule for project

management is provided in *SOP 16: Data Management*. The database architecture, tables, and attributes, and their features are provided in *SOP 16: Data Management*. An overview of the database management strategy is provided in the following section.

4.2. Overview of Database Design

A customized relational database application, implemented in Microsoft Access, will be designed to store and manipulate the data associated with this project along with an identical working database to facilitate data entry and quality control and assurance of field collected data prior to uploading to the master database. The design of these databases will be consistent with NPS I&M Natural Resource Database Template version 3.2 (NPS 2007) and MOJN I&M standards. Once implemented, the databases will continue to undergo revisions, which will be reflected in *SOP 16: Data Management*. The general database strategy is to use a blank version of the protocol database (a “working copy”) to enter, error-check, and validate a given season’s data, then migrate that data to the read-only “master version” of the protocol database. This strategy protects validated data from corruption, and the master version will facilitate multi-year analyses. The underlying data structure (tables, fields and relationships) will always remain the same in both master and annual working versions, with the working blank structure updated on an annual basis as the protocol develops and the master structure is adapted. Details of the databases, including a description of core and peripheral tables and a logical model of table relationships, are presented in *SOP 16: Data Management*. The database, upload procedure for electronic data collection devices, and the data entry forms will all include quality controls. Following data upload and any subsequent data processing or changes to the data, the data will undergo quality assurance review process.

4.3. Preparation

Network protocols require a mix of application, documents, equipment, and general field preparations before the field season is initiated. The annual working database must be created and updated for changes in the protocol from the previous season. SOPs must be updated as well, especially field procedure SOPs and lessons learned during the time when the data are processed, reviewed for quality, analyzed, and archived. Changes in the field datasheets must be reconciled with the master and working database structure and the working database data entry forms.

4.4. Data Acquisition

The MOJN I&M Selected Large Springs protocol integrates many different monitoring activities into a single protocol, resulting in several different types of data sources that are collected via differing methods, formats, and temporal intervals. In addition, the SLS protocol may be conducted in conjunction with MOJN I&M Riparian Vegetation protocol, which will not be discussed in this document. The following list summarizes the data types for SLS protocol field collection:

- Core water quality parameters, discrete collection
- Water chemistry
- Water discharge, both continuous and discrete collection

- Benthic macroinvertebrates
- Photographs

Discrete water quality data, water level (discharge) data, and temperature data will be entered into the MOJN I&M Access databases promptly after retrieval to check for outliers and erroneous data. Continuous data logger sources will be uploaded to proprietary software packages promptly after retrieval to check for outliers and erroneous data. Water chemistry and macroinvertebrate identification data will be obtained from contract laboratories and will be uploaded digitally if possible when submitted from the laboratory to MOJN I&M. Photographs will be downloaded periodically throughout the season to the appropriate receiving folders on the network. If the data are not provided in a format that lends itself to a digital upload, then MOJN I&M staff will enter all information into the database. Other information will be entered into the database by MOJN I&M staff from either hard copy or electronic field sheets.

4.5. Data Entry

Data entry forms in the MS Access annual working database are designed for ease of use, i.e. similar appearance to field datasheets, efficiency, and quality control. Examples of data entry associated with this protocol are discrete field data collection from site visits, water quality metadata, image metadata, and laboratory sample data results.

4.6. Quality Review

There are two stages of quality review associated with data acquisition. The first stage in quality assurance is the Field Data Quality Assurance, which includes the following procedures:

1. Review field datasheets for omissions or obvious errors prior to data entry.
2. Following data entry, cross-reference sample events table with field datasheets.
 - Action: Investigate and resolve any discrepancies.
3. Verify 100% of the data entry values with field data sheets.
 - This can be accomplished by a second data-entry individual.
4. *AND* cross check at least 10% of the data entry values with the field data sheets.
 - Performed by the Data Manager or the Protocol Lead.

4.6.1. Implement MS Access Queries to Test for Generic Errors

After the data have been entered and processed according to the Stage 1 procedures listed above, the data need to be reviewed by the Protocol Lead for quality, completeness, and logical consistency. The working database application will facilitate this process by showing the results of pre-built queries that check for data integrity, data outliers and missing values, and illogical values. The user may then fix these problems and document the fixes. If all errors and inconsistencies cannot be fixed, the resulting errors will be documented and included in the metadata and certification report.

Additional quality reviews are conducted within the proprietary software used to process and analyze water quality and water quantity data. Correct procedures are documented by the software and archived as outlined below in the Archiving section. Finally, all data are subject to the QAPP, detailed in this protocol's *SOP 13: Quality Assurance Project Plan*.

Water data submitted to the NPS Water Resources Division via the NPS EQuIS electronic data deliverable (EDD) specification will undergo a final review by the EQuIS Data Processor before it is incorporated into the Servicewide EQuIS database and transferred to the STORET Data Warehouse (Figure 33). Data corrections, adjustments, and errors will be documented; corrected data will be updated in the network database and resubmitted via the NPS EQuIS EDD, if necessary.

4.7. Metadata

Data documentation is a critical step toward ensuring that both spatial and non-spatial datasets are useable for their intended purposes well into the future. This involves the development of metadata, which can be defined as structured information about the content, quality, and condition of data. Additionally, metadata provides the means to catalog datasets within intranet and internet systems, making data available to a broad range of potential users. Metadata for all MOJN I&M monitoring data will conform to Federal Geographic Data Committee (FGDC) and NPS guidelines and will contain all components of supporting information such that the data may be confidently manipulated, analyzed, and synthesized. Refer to the following for additional guidelines:

1. MOJN-DM-SOP Documentation Spatial
2. MOJN-DM-SOP Documentation Non-Spatial

For long-term projects such as this one, metadata creation is most time consuming the first time it is developed; after which most information remains static from one year to the next. Metadata records in subsequent years then only need to be updated to reflect current publications, references, taxonomic conventions, contact information, data disposition and quality, and to describe any changes in collection methods, analysis approaches or quality assurance for the project.

In addition to the standards outlined in the *MOJN-DM-SOP Documentation Spatial* and *MOJN-DM-SOP Documentation Non-Spatial*, this protocol will provide metadata for all measured parameters that will meet the standards of EPA STORET for water quality reporting. The Protocol Lead and the Data Manager (or data technician) will work together to create and update an FGDC- and NPS-compliant metadata record in XML format. The Protocol Lead should update the metadata content as changes to the protocol are made, and each year as additional data are accumulated. Edits within the document should be tracked so that any changes are obvious to those who will use it to update the XML metadata file. At the conclusion of the field season, the Protocol Lead will be responsible for providing a completed, up-to-date metadata interview form to the Data Manager. The Data Manager will facilitate metadata development by creating and parsing metadata records, and by posting such records to national clearinghouses as described below.

4.8. Sensitive Information

Part of metadata development includes determining whether or not the data include any sensitive information, which includes specific locations of rare, threatened, or endangered species. Prior to completing metadata, the Protocol Lead and park resource manager should work together to identify any sensitive information in the data. Their findings should be documented and communicated to the Data Manager. We do not anticipate that sensitive information will be present in the Selected Large Springs monitoring program at this time.

4.9. Data Certification

Data certification is a benchmark in the project information management process that indicates that 1) the data are complete for the period of record; 2) they have undergone and passed the quality assurance checks; and 3) that they are appropriately documented and in a condition for archiving, posting, and distribution. Certification is not intended to imply that the data are completely free of errors or inconsistencies which may not have been detected during quality assurance reviews. To ensure that only data of the highest possible quality are included in reports and other project deliverables, the data certification step is an annual requirement for all tabular and spatial data. The Protocol Lead is primarily responsible for completing certification with the assistance of the Data Manager. Additional details of the certification and delivery processes are included in *MOJN-DM-SOP Data Quality*.

4.10. Data Delivery

After the data are certified by the Protocol Lead, the Data Manager will transfer all data from the annual working database to the master database and deliver the data to the Protocol Lead.

4.11. Data Analyses and Product Development and Delivery

The project lead is responsible for data analyses, product development, and delivery of the products to the Data Manager. Analyses and products are discussed in Section 5, Data Analysis and Reporting. Reports and delivery schedules are detailed in *SOP 15: Data Analysis and Reporting*. All documents associated with analyses and products are delivered to the Data Manager for posting and distribution. The organization and general standards for project deliverables are detailed in *MOJN-DM-SOP Project Deliverables*.

4.12. Posting and Distribution

Data and reports are posted on the MOJN I&M website, and to the NPS Data Store (<http://irma.nps.gov>).

The water quality component of the Natural Resource Challenge (NRC) requires that networks archive all physical, chemical, and biological water quality data collected with NRC water quality funds in the Environmental Protection Agency's STORET Data Warehouse. The precursor to entry in the STORET Data Warehouse is entry in the NPS' Servicewide EQuIS database from which all data are automatically transferred to STORET. All water quality data collected by MOJN I&M will be managed according to guidelines from the WRD for upload into EQuIS and transfer to STORET. This includes mapping and converting park and network water quality data into the specified EQuIS EDD format with appropriate metadata, as prescribed by WRD. MOJN I&M data management staff

will upload all network water quality data, in the EQuIS EDD format, to EQuIS at least annually. From EQuIS, the data will flow automatically to the STORET Data Warehouse (Figure 33).

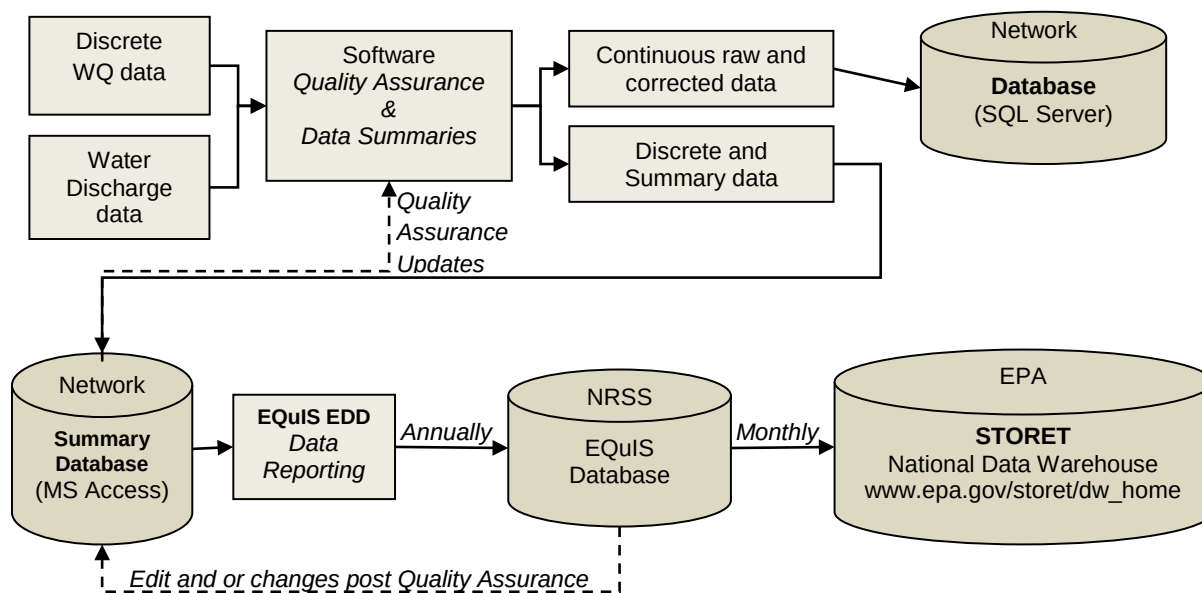


Figure 33. Data flow diagram for water quality data.

4.13. Archiving and Records Management

Upon certification by the Protocol Lead, digital and non-digital data will be archived as outlined in the *MOJN-DM-SOP Archiving*. ASCII comma-delimited text files are created for each data table within a database and for all datasets derived from electronic data collection devices. These files are accompanied by a well-documented data dictionary that explains the contents of each file, file relationship, and field definitions. *SOP 16: Data Management* includes a detailed list of the data-related files that will be archived. Master databases and annual project deliverables and reports will be archived on the MOJN I&M server which is maintained and subject to NPS Lake Mead National Recreation Area IT department back-up procedures.

4.14. Season Closeout

A review of archive and expendable data products will be undertaken by the Protocol Lead and Data Manager during an annual close-out session to ensure that all data, metadata, and documents are properly organized, archived, and disseminated to the appropriate locations. Decisions concerning what to retain and what to destroy will follow the guidelines stipulated in NPS Director's Order 19 (NPS 2001). An example of an expendable data product is an intermediate draft of a biennial report that was saved during report preparation and may be discarded once the final report is generated. Details pertaining to season closeout are provided in *MOJN-DM-SOP Season Closeout*.

5. Data Analysis and Reporting

Data analysis approaches were developed in concert with sample design development and power analysis simulations. The Protocol Lead is responsible for performing the data analyses including descriptive statistics and statistical tests of trends through time. *SOP 15: Data Analysis and Reporting* provides a detailed description of the procedures described here.

5.1. Quality Assurance/Quality Control

SOP 13: Quality Assurance Project Plan (QAPP) is the written record of the QA/QC program. Quality assurance (QA) refers to the overall management system which includes the organization, planning, data collection, quality control, documentation, evaluation, and reporting activities of the group. QA provides the information needed to ascertain the quality of data and whether it meets the requirements of the program. QA ensures that data will meet defined standards of quality with a stated level of confidence. Quality control (QC) refers to the routine technical activities whose purpose is error control. The procedures carried out specifically for QA/QC purposes are fully described in the QAPP. The key procedures for each data type are given in Table 22.

Table 22. Key QA/QC procedures.

Data Type	Key QA/QC Procedures
Water Quality Data	• Annual alternative measurement sensitivity plus (AMS+) measurements • Calibration and calibration checks
Continuous Discharge	• Training field staff using standard USGS methodology • Maintenance of flumes and weirs • Check weirs and flumes vs. volumetric measurements • Check transducer readings against field readings
Benthic Macroinvertebrates	• Extensive set of procedures followed by USU BugLab
Water Chemistry	• Extensive set of procedures followed by laboratory • Submittal of duplicate samples to laboratory
Springsnails Monitoring	• Retain samples for expert review, if necessary
Monitoring Wells	• Triplicate measurements, same measuring point used each time • Surveying elevations annually

5.2. Data Processing

Some of the measurements made by MOJN I&M require processing before they can be interpreted (Table 23). Many of the data processing steps can be performed at the time that the biennial report is prepared. However, the continuous discharge records, which are downloaded quarterly, should be reviewed as soon as possible so that any problems can be remedied quickly.

Table 23. Annual data analysis procedures.

Data Type	Processing	Outputs for Reporting
Continuous Discharge	Processing stage records using USGS procedures	Graphs of daily mean for each continuously-monitored spring
	Conversion to discharge using flume or weir equations	Table of monthly mean, min, max for each continuously-monitored spring
Quarterly Discharge	Calculation of mean (volumetric measurement)	Graph and table of measured values in all springs over time
	Conversion to discharge using flume equations (temporary flume)	
Benthic Macroinvertebrates	USU BugLab calculates four basic indices	Table of indices in all springs over time
Water Chemistry and Water Quality	None	Table of all parameters in all springs over time
Springsnail Monitoring	None	Graph of counted springsnails vs. position for each spring Table of furthest downstream observation in all springs over time
Monitoring Wells	Subtract depth-to-water from elevation	Graph and table of water level measurements

5.3. Trend Analysis

The data collected for the SLS protocol will be plotted and reported annually, but there will be insufficient data for formal statistical analysis for some time. The USGS recommends that “The period of record for stations included in a trend study should be at least five years for monthly data or longer for less dense data” (Schertz et al. 1991). Trends that impact all of the streams or all of the lakes will be detectable more rapidly than trends that impact a single station. However, it will be several years before the data can be analyzed for trends using statistical methods. Trend analyses will be performed every four years once there is a minimum of five years of data, but they may be calculated more frequently if requested by NPS resource managers. For parameters measured biennially, five data points should be collected before trends are analyzed. The trend analyses that will be performed are summarized in Table 24.

5.3.1. Parametric vs. Non-Parametric Trend Testing

There are two general types of trend analyses that will be performed on the MOJN I&M Selected Large Springs data (Table 24): mixed-model parametric trend-testing and non-parametric trend testing using various Kendall tests.

The mixed-model parametric trend tests used in the Power Analysis section (Section 2.3) assume that the observed data are the sum of a linear trend and normally-distributed residuals, and use t-testing to evaluate the significance of the trends. Kendall-type tests assume that the trend in the data is monotonically increasing, but not necessarily linear, and make no assumptions regarding the distribution of the residuals.

A USGS study (Hirsch et al. 1991) compared the power of parametric and non-parametric analyses on simulated water quality data, and found that parametric trend tests were slightly more powerful than non-parametric trend tests for normally-distributed data, but much less powerful for data where the assumption of normality was not justified. The study concluded that:

“In light of these kind of results, which show that the non-parametric procedures suffer only small disadvantages (in terms of efficiency or power) in the normal case, potentially modest advantages when the data depart slightly (perhaps imperceptibly) from normality, and large advantages when they depart a great deal from normality...: we have chosen to apply non-parametric procedures routinely in studies involving multiple data sets.”

Water quality data are not generally normally-distributed, and transforming them to a normal distribution may be difficult due to the large number of extreme values (Hirsch et al. 1991). Therefore, all of the water quality data will be tested for trends using non-parametric methods on untransformed data values (Table 24). However, the power analyses of historical data (section 2.3) indicate that discharge records in selected large springs are amenable to parametric trend testing. In addition, the timely detection of trends in discharge due to potential future groundwater withdrawals is a high priority for this protocol. Therefore, both parametric and non-parametric tests will be used to test the spring discharge data for trends (Table 24). This duplication is in accordance with the recommendations of Irwin (2008), who emphasizes the importance of multiple lines of evidence in statistical inference.

5.3.2. Trend-Testing Methods

Parametric testing will be conducted using the mixed model described in section 2.3 (VanLeeuwen et al. 1996; Piepho and Ogutu 2002). A mixed model allows some effects to be considered fixed and some to be considered random. Fixed effects contribute to the mean of the outcome, and random effects contribute to the variance. Random effects are used to estimate variation of linear trends among subjects (e.g., springs) and over time. Piepho and Ogutu (2002) improve the estimator proposed by VanLeeuwen et al. (1996) by modeling the site effect as fixed or random. A random site effect may be modeled as correlated with the random slope for each site. The ability to modify the assumptions provides additional benefits of trend test invariance and model flexibility. The mixed model will be implemented using an R script written by L. A. Starcevich.

The Mann Kendall Test (MKT) is a statistical method used to assess trends in data sets. The advantages of this test are that it is widely-used, non-parametric, and applicable to any type of monotonically-increasing trend (i.e., not just linear increases). MKT will be used for all of the parameters that are measured on a biennial basis.

The Seasonal Kendall Test (SKT) is used to detect trends in seasonally-variable data (e.g., Hirsch et al. 1982). The data are binned into seasons by the user, and MKT is performed for each season. The results from all seasons are then combined into a single test. A correction for serial correlation may be necessary if 10 or more years of data are available (Hirsch and Slack 1984). The SKT will be used to analyze trends in spring discharge and the quarterly water quality data.

The statistical analyses using MKT and SKT will be conducted using kendall.exe, a software program available from the USGS (Helsel et al. 2006).

More details on the implementation of these methods are given in *SOP 15: Data Analysis and Reporting*.

Table 24. Trend analysis procedures.

Data Type	Measureable Objective (Section 1.3.2)	Trend Analysis Method
Spring Discharge	Determine the status, trend, and natural range of variability in spring discharge	Parametric (mixed-model) trend testing and SKT testing for seasonally-weighted mean discharge for each spring
Benthic Macroinvertebrates	Determine the status and trend in spring macroinvertebrate assemblages	MKT of basic indices for each spring
Water Quality and Water Chemistry	Determine the status, trend, and natural range of variability in spring water chemistry	SKT for water quality and MKT for water chemistry for each spring
Springsnails	Determine the status and trend in the population and spatial extent of springsnails	MKT for furthest downstream observation and mean population density. Qualitative evaluation of changes in population density vs. distance downstream.
Monitoring Wells	Determine the status and trend in the water levels in monitoring wells relevant to selected large springs	MKT trend testing for seasonally-weighted water level for each well.

5.4. Automated Reports

In an effort to make data available to park managers in a timely fashion, MOJN I&M will develop a web application for automated reporting. The application will allow park staff to select springs from a map, then produce plots or tables of discharge or water quality parameters over time. Certified data will be made available for reporting on a quarterly basis.

The application will be developed using Rshiny, a web application package for R, and will be hosted on an NPS server in Fort Collins, Colorado. Initially, the application will only be accessible to NPS personnel.

5.5. Biennial Reports

The program will produce a report for the springs in each park every two years, once the laboratory data for the park is available. The report will be published in the NPS Natural Resource Data Series, and will include all the discharge, water quality, water chemistry, BMI, and springsnail data produced in the park since the last report. Reports will be distributed to NPS-WRD, network staff, Resource Chiefs, the MOJN Technical Committee, and the MOJN Water Resources Working Group. Reports will also be made available to interested park staff and the public via IRMA. The biennial reports will include the following information:

- Description of field work in the park highlighting accomplishments

- Documentation of any deviations from the protocol, such as missed sites or samples
- Results from the past two years, including raw data, summary statistics and graphics
- Quality assurance and quality control analyses

The data summary products described in Table 24 will be included in the biennial report. Samples of some of these products are given in *SOP 15: Data Analysis and Reporting*.

5.6. Data Synthesis Reports

Data synthesis reports will be prepared for each park every four years. In addition to summarizing the collected data, these reports will include the following information:

- Overview of the protocol status and major accomplishments
- Status and trend analysis results
- Discussion of results, including management implications
- In depth, quality assurance and quality control analysis and discussion
- Recommendations for future improvements.

The specific details of report content will be determined by the protocol lead at the time of report preparation.

5.7. Protocol Review

Protocol implementation success will be thoroughly reviewed by network staff and the Water Resources Working Group following the first year of implementation. Thereafter, the program will be formally reviewed and evaluated every four years, shortly after the preparation of the quadrennial trend analysis report has given network personnel a sense of the effectiveness of the monitoring program.

6. Personnel Requirements and Training

6.1. Personnel Requirements

This protocol requires close collaboration between MOJN I&M staff and the staff of the network parks. The Protocol Lead will be the MOJN I&M Hydrologist. Other key staff members include the MOJN I&M Program Manager, MOJN I&M Data Management Team, MOJN I&M Biological Science and/or Hydrologic Technician(s), GRBA Fisheries Staff, DEVA Hydrology Staff, PARA Physical Scientist, and contract laboratories responsible for the analysis of water chemistry and macroinvertebrate samples.

MOJN I&M's Hydrologist serves as the Protocol Lead for the network's aquatic resource monitoring. The Hydrologist is supervised by the MOJN I&M Program Manager and frequently interacts with the network Data Management Team to coordinate database development and data archiving. We anticipate that approximately one third of the Hydrologist's effort will go toward implementing and refining this protocol, with the remainder of the time spent on the Streams and Lakes, Weather and Climate, and Arid Lands Springs protocols. The duty station for the position is the MOJN I&M office at LAKE.

6.2. Roles and Responsibilities

As Protocol Lead, the Hydrologist will coordinate data collection, sample processing, and archiving of data as well as perform data analysis and reporting. The Protocol Lead will spend four days in the field each quarter, with visits to the selected springs in JOTR, MOJA, PARA, and LAKE and the monitoring well in LAKE. In addition, the Protocol Lead is responsible for ensuring that the required field work occurs at DEVA and GRBA. Visits to these two parks may be necessary to coordinate with park personnel and to collect BMI and water chemistry samples and monitor springsnail populations.

The MOJN I&M Program Manager will supervise the Hydrologist and provide overall administrative and scientific leadership for all monitoring activities.

The MOJN I&M Data Management Team (the Data Manager, Assistant Data Manager, and GIS Specialist) will develop and maintain the databases for the monitoring data generated by this protocol, maintain data management SOPs, maintain all data for the protocol, and upload water quality data to national databases (e.g., EPA STORET).

The MOJN I&M Biological Science and/or Hydrologic Technician(s) will monitor springs with the Hydrologist each quarter. They may also assist the Hydrologist in other tasks as needed and available.

The GRBA Fisheries Staff will collect discharge and water quality data from the selected springs in GRBA, and monitor water levels in the Baker Creek Road well.

The DEVA Hydrology Staff will collect or supervise the collection of data from the selected large springs in DEVA.

The PARA Physical Scientist will accompany the Hydrologist to the two selected large springs in PARA each quarter.

The roles of park and network staff in the data collection activities at each park are summarized in Table 25. The roles and responsibilities of all personnel are summarized in Table 26.

Table 25. The roles of park staff and MOJN I&M staff in SLS protocol data collection at each park.

Park	Park Role	MOJN I&M Role
DEVA	DEVA Hydrology Staff monitors discharge and water quality at all springs	Water chemistry, BMI and springsnail monitoring
GRBA	GRBA Fisheries Staff monitors discharge and water quality at all springs and water levels in monitoring well	Water chemistry and BMI monitoring
JOTR		- MOJN I&M tech monitors discharge and water quality with JOTR tech - Discharge, water quality, water chemistry, and BMI monitoring
LAKE		Discharge, water quality, water chemistry, BMI, and springsnail monitoring, water level monitoring in well
MOJA		Discharge, water quality, and water chemistry monitoring
PARA	PARA Physical Scientist monitors discharge and water quality with MOJN I&M Hydrologist	- MOJN I&M tech monitors discharge and water quality with PARA Physical Scientist - Water chemistry, BMI, and springsnail monitoring

Table 26. Roles and responsibilities for implementing the MOJN I&M SLS protocol.

Role	Responsibilities
Protocol Lead	• Manages project oversight and administration. • Collaborates with network Program Manager on tracking project objectives, budget, personnel requirements, and progress toward meeting monitoring objectives. • Facilitates communications with NPS resource managers. • Coordinates and ratifies changes to protocol. • Coordinates field work. • Performs monitoring at LAKE, MOJA, JOTR, and PARA. • Collects or supervises the collection of biennial water chemistry and BMI samples and springsnail population monitoring. • Supervises macroinvertebrate sample processing. • Performs data summaries and analyses. • Maintains and archives project records. • Manages project operations and implementation. • Certifies each season's data for quality and completeness. • Completes reports, metadata, and other products according to schedule.
Program Manager	• Provides supervision and oversight of the Protocol Lead. • Manages administration and budget. • Consults on all phases of protocol review and implementation. • Reviews annual and 4-year reports.
Data Management Team	• Consults on data management activities. • Facilitates check-in, review, and posting of data, metadata, reports, and other products to national databases (e.g., EPA STORET) according to schedule. • Maintains and updates database application. • Provide database training as needed. • Serves as primary steward of Access database and GIS data and products.
Biological Science and/or Hydrologic Technician (s)	• Assists Protocol Lead with field work in LAKE JOTR, MOJA, and PARA. • Assists with data compilation, data entry, field QA/QC, and field equipment management, as needed.
GRBA Fisheries Staff	• Collects discharge and water quality data at GRBA Springs. • Monitors water levels in Baker Creek Road Well.
DEVA Hydrology Staff	• Collects discharge and water quality data at DEVA springs.
PARA Physical Scientist	• Aids the Protocol Lead in data collection at selected large springs in PARA.
Taxonomists and Chemistry Labs	• Identifies and enumerates macroinvertebrates, according to protocols. • Performs water chemistry analyses. • Certifies QA/QC.

6.3. Qualifications and Training

The Hydrologist will meet the basic requirements for a GS-12 Hydrologist. Education and/or experience in data analysis, field sampling, and water quality assessment are required. Experience with wilderness travel and backcountry safety is desired.

Details on training for safety, the protocol methods, and park specific training requirements are outlined in *SOP 1: Safety* and *SOP 2: Staff Training*.

6.4. Facilities, Equipment, and Vehicles

No specialized facilities are needed to support the protocol field work.

The discharge monitoring component of the protocol will likely require the installation of a permanent flume at Pakoon Springs. The flume will be installed during the spring rehabilitation process currently being planned by PARA. The flume and the vented pressure transducer installed at the spring will be provided by MOJN I&M.

The water quality component of the protocol requires the use of three handheld water quality meters: one owned by MOJN I&M, one used by GRBA, and one used by DEVA. Ideally, the same instrument would be used for all springs. In practice, however, the analysis of trends in water quality across springs in different parks is not a major goal of the protocol (Table 24), so the logistical difficulties of using a common instrument outweigh the benefit of a slight increase in data comparability.

The miscellaneous equipment required for the BMI sampling and springsnail population monitoring will be provided by MOJN I&M.

One of MOJN I&M's 4WD vehicles will generally be used for monitoring. The GRBA crew will use a GRBA vehicle.

7. Operational Requirements

7.1. Annual Workload and Schedule

The annual workload of this monitoring protocol is outlined by the tasks listed below in Table 27. The annual start-up for water quality monitoring begins in January with the final reporting, review and other close-out activities for the previous year. Field work is conducted year round, although summer field work during heat waves or winter field work in snow conditions will be avoided.

The schedule is coordinated with the annual schedule for the Streams and Lakes Protocol, with little activity scheduled for GRBA's June-to-September field season.

Table 27. Annual implementation schedule for MOJN I&M SLS protocol.

Month	Administration	Field Work	Data Management
January	Process Q4 discharge records.		Reconcile and upload laboratory results to database
February	Submit drafts of biennial reports to MOJN I&M Program Manager	Water chemistry, BMI, and springsnails at-DEVA (odd years)	Season close-out
March	Complete required permitting reports (IARs).	Quarterly field visits to LAKE, PARA, MOJA, and JOTR Discharge and WQ at GRBA (Marmot Spring only) Water chemistry, BMI, and springsnails at PARA, and LAKE (odd years) or JOTR and MOJA (even years)	Update protocol and data management SOPs
April	Process Q1 discharge records		Compile data needs for IARs
May	Review laboratory results.		Compile and submit data to STORET
June		Quarterly field visits to LAKE, PARA, MOJA, and JOTR Discharge and WQ at GRBA	Coordinate data acquisition Initiate data entry – hire/train technician Upload device data
July	Process Q2 discharge records.		Coordinate data acquisition Continue data entry coordination Upload device data
August			Coordinate data acquisition Continue data entry coordination Upload device data
September		Quarterly field visits to LAKE, PARA, MOJA, and JOTR Discharge and WQ at GRBA Water chemistry and BMI at GRBA (even years)	Coordinate data acquisition Continue data entry coordination Upload device data

Table 27. Annual implementation schedule for MOJN I&M SLS protocol (continued).

Month	Administration	Field Work	Data Management
October	Process Q3 discharge records		Coordinate data acquisition Continue data entry coordination Upload device data Close out MOJN I&M field gear Compile discrete data for Protocol Lead
November			Certify data Copy data to visualization platforms and geodatabases
December		Quarterly field visits to LAKE, PARA, MOJA, and JOTR	

7.2. Budget

The estimated annual operating budget for the Springs Protocol is provided in Table 28.

Table 28. Estimated SLS protocol budget.

Annual Estimates		Annual Cost
Analyses and Equipment		
Laboratory analyses	Water Chemistry	1,500
	BMI	2,100
	Shipping & Supplies	1,000
Vented pressure transducer replacement (replace 1 / year)		1,000
Water quality instrument maintenance and standards		400
Total for Analyses and Equipment		6,000
Labor		
Hydrologist (0.33 time/year)		21,450
Science Technician (2 pay period)		2,600
DEVA Staff and vehicle (In-kind contribution from park)		10,000
GRBA Staff and vehicle (In-kind contribution from park)		1,500
PARA Staff and vehicle (In-kind contribution from park)		1,000
Data Management		
Data Manager (321 hrs)		13,771
Data Management Technician (64 hrs)		1,469
GIS Specialist (68 hrs)		2,156
Travel		1,500
Total Annual Cost		61,446

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