



Springs in the Mojave Desert Network— Surface Water Monitoring at Desert Springs

Protocol Narrative Version 1.0

Natural Resource Report NPS/MOJN/NRR—2018/1718



ON THE COVER

Looking down at Corkscrew Spring in Death Valley National Park.
Photograph courtesy of the National Park Service.

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Executive Summary

The National Park Service (NPS) created the Inventory and Monitoring (I&M) Program to collect and analyze data on the status and trends of natural resources within ecoregional networks. This protocol describes methods to monitor surface water at springs in the Mojave Desert Network (MOJN), including Death Valley National Park, Joshua Tree National Park, Mojave National Preserve, Lake Mead National Recreation Area, and Grand Canyon-Parashant National Monument. The primary measurable objectives for this protocol are:

- Determine the status and trends of water availability (flow condition, discharge, and surface water dimensions) at a subsample of springs in each of the five monitored parks.
- Determine the status and trends of water quality (temperature, pH, dissolved oxygen, and specific conductance) at a subsample of springs in each of the five monitored parks.

Springs are selected at each park using a Generalized Random Tessellation Stratified (GRTS) spatially-balanced random sample. Quantitative measurements of water availability and water quality will be made each time the springs are visited in order to detect changes over time. A smaller number of springs will be visited more frequently and will be equipped with data-logging sensors to provide continuous records of the seasonal presence of surface water.

This protocol also includes qualitative measurements of site condition that can be collected rapidly during spring visits. Because network staff will often be the only NPS staff visiting the springs regularly, these qualitative measurements will provide park managers with important and useful information about spring resources that would not be collected otherwise. Information on site condition includes qualitative measurements of dominant vegetation, invasive plants, and disturbance, as well as repeat photographs.

This protocol consists of a narrative and a set of standard operating procedures, which detail the steps required to collect, manage, and disseminate the data. Data collected for this protocol, along with other monitoring protocols, will provide a context for interpreting the status and trends of natural resources within the network. More intensive monitoring of high priority springs chosen by park managers is addressed in a separate protocol.

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As previous MOJN I&M Program Managers, Kristina Heister and Alice Chung-MacCoubrey laid the groundwork for water-related protocols in the network. This document also uses content from previous network publications, particularly the MOJN I&M Vital Signs Monitoring Plan (Chung-MacCoubrey et al. 2008).

This protocol drew from methods developed for MOJN I&M by Don Sada and Karl Pohlmann of the Desert Research Institute. Don Sada was also instrumental in leading the initial spring inventory for the network.

MOJN I&M has worked with other I&M networks in the Southwest (Chihuahuan Desert Network, Northern Colorado Plateau Network, Sonoran Desert Network, and Southern Colorado Plateau Network) to standardize how certain measurements and observations are made. We thank the Data Managers and Protocol Leads at these networks, as well as staff from the Inventory and Monitoring Division at the Washington Support Office (WASO) in Fort Collins, Colorado.

This document benefited from the thoughtful reviews of Dr. Jon Bakker of the University of Washington, Lisa Garrett of the NPS Inventory and Monitoring Program, Dean Tucker, and Peter Penoyer of the NPS Water Resources Division, and an anonymous reviewer.

List of Acronyms

DEVA	Death Valley National Park
DS	Desert Springs
EPMT	Exotic Plant Management Team
EQuIS	Environmental Quality Information System
GLMM	General Linear Mixed Model
GRTS	Generalized Random Tessellation Stratified
I&M	Inventory and Monitoring Program
IMD	Inventory and Monitoring Division
IPSED	Invasive Plant Species Early Detection
IRMA	Integrated Resource Management Applications Portal
JHA	Job Hazard Analysis
JOTR	Joshua Tree National Park
LAKE	Lake Mead National Recreation Area
MOJA	Mojave National Preserve
MOJN	Mojave Desert Network
NISIMS	National Invasive Species Information Management System
NPS	National Park Service
PARA	Grand Canyon-Parashant National Monument
QA / QC	Quality Assurance / Quality Control
SOP	Standard Operating Procedure
STORET	Storage and Retrieval Data Warehouse
USGS	United States Geological Survey
WQ	Water Quality
WRD	Water Resources Division

1. Background, Rationale, and Objectives

1.1 The Mojave Desert Network

1.1.1 Location of the MOJN Parks

The NPS Natural Resource Inventory & Monitoring (I&M) Program was created by Congressional mandate in 1998 to provide park managers with a broad-based understanding of the status and trends of natural resources to be used in making management decisions, working with other agencies, and communicating with the public (NPS 2015).

The I&M Program consists of 32 ecoregional networks where natural resource inventory and monitoring activities are conducted. The Mojave Desert Network (MOJN) includes nine NPS units (Figure 1): Castle Mountains National Monument (CAMO), 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 cover 3.4 million hectares, making MOJN the largest network by area in the contiguous United States.

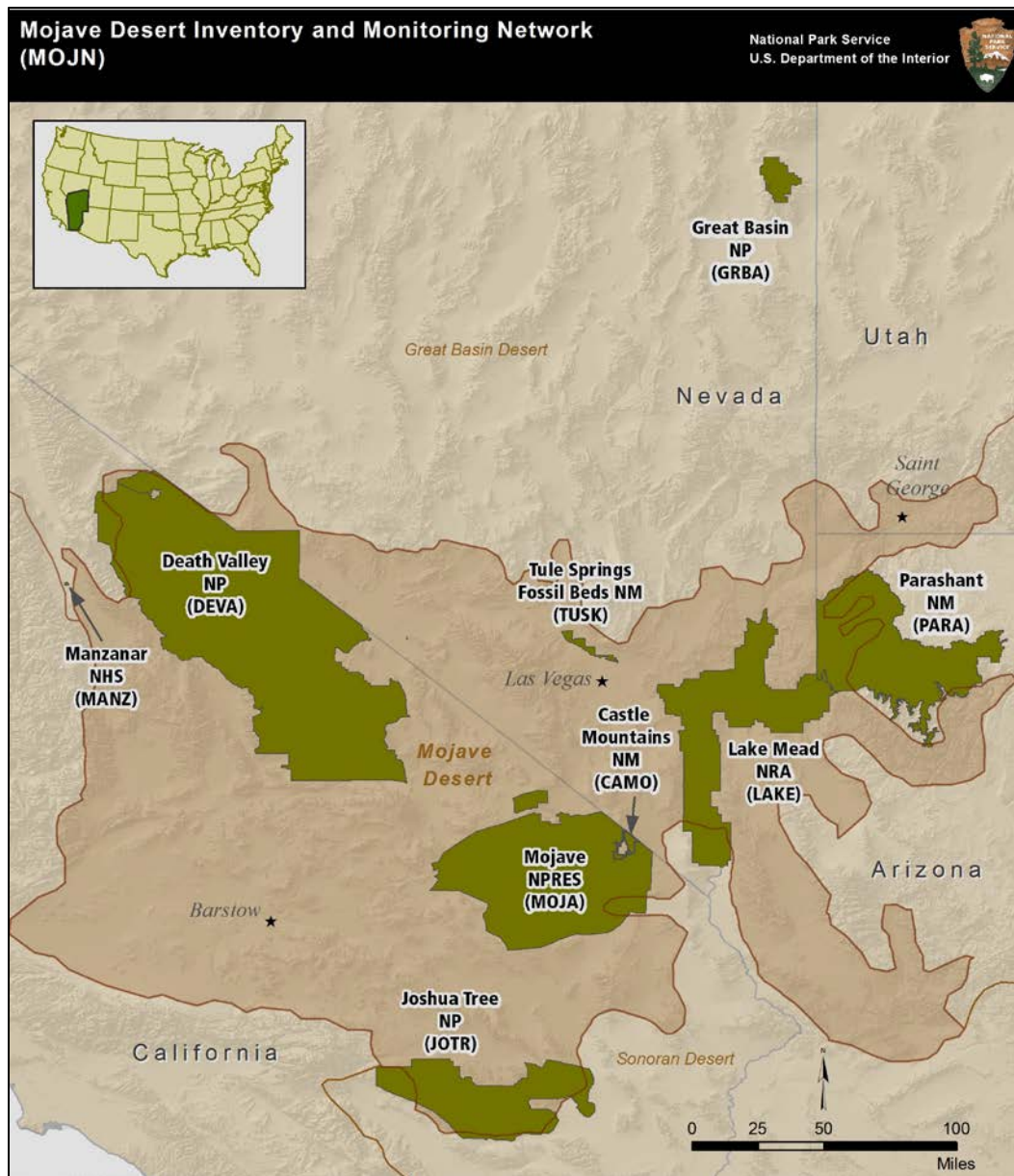


Figure 1. NPS units of the Mojave Desert Network.

1.1.2 Geography of the MOJN Parks

The nine MOJN parks encompass more than 3.4 million hectares of land within three semi-arid desert ecosystems (Mojave, Great Basin, and Sonoran) across three states (Arizona, California, and Nevada). There is a gradient of increasing temperature and decreasing elevation from north to south over the network. Throughout the larger parks, considerable topographic relief generates different climate regimes due to the interaction of air density, solar radiation, precipitation, and slope. In turn, these local climate regimes strongly influence the availability of surface water and the distribution of plant and animal communities.

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. At the five parks monitored for this protocol (DEVA, JOTR, LAKE, MOJA, and PARA), desert springs often represent the only available surface water over sizable areas.

Table 1. Area, elevation range, and surface water resources of the MOJN parks.

Park	Area (ha)	Elevation Range (m)	Permanent Rivers	Headwater Streams	Ponds & Lakes	Reservoirs	Springs
Castle Mountains NM (CAMO)	8,466	1193–1689	0	0	0	0	2
Death Valley NP (DEVA)	1,374,420	-86–3,368	0	0	0	0	814
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 (~1 ha or less)	87
Lake Mead NRA (LAKE)	521,346 ^a	152–1,719	3	1	0	2 large (~11,000 ha, ~64,000 ha)	86
Manzanar NHS (MANZ)	329	1,158	0	0	0	0	0
Mojave N. Pres. (MOJA)	619,923	274–2,438	0	0	0	0	215
Grand Canyon-Parashant NM (PARA)	424,242 ^b	366–2,447	0	0	0	0	197
Tule Springs Fossil Beds NM (TUSK)	9,166	645–1,008	0	0	0	0	0

^a 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.

^b 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.

The geographies of the five parks monitored for this protocol are summarized briefly below; an overview of their aquatic resources follows in the next section. CAMO, MANZ, TUSK, and GRBA are not included in this protocol and are not discussed further.

Death Valley National Park was established as a National Monument in 1933 and then as a National Park in 1994. DEVA covers 1.37 million hectares and is the largest NPS unit in the contiguous United States. The park includes the southern boundary of the Great Basin Desert and the northern boundary of the Mojave Desert. DEVA includes the lowest point in North America (Badwater, 86 m below sea level), receives the least precipitation in the United States (Furnace Creek, 5.5 cm per year), and claims the highest recorded temperature in the world (Furnace Creek, 57° C). Two

mountain ranges flank DEVA to the west and east, producing dramatic topographic relief. Because hot desert species are found at the lower elevations and cold desert species are found at the higher elevations, DEVA supports diverse assemblages of flora and fauna. Habitats such as springs, drainages, playas, sand dunes, and subterranean pools are home to a number of endemic species that have adapted to the unique and harsh environments found in the park (e.g., Devils Hole pupfish, [*Cyprinodon diabolis*]).

Joshua Tree National Park was established as a National Monument in 1936 and then as a National Park in 1994. JOTR covers more than 320,000 hectares and is the southern-most park in MOJN. The park lies at the transition between the Mojave Desert and Sonoran Desert and includes a portion of the west-east oriented Transverse Ranges. In this transition zone between ecosystems, the park supports unique assemblages of flora and fauna. Five of North America's 158 desert fan palm oases occur in JOTR. Many species, especially reptiles, are 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 founded as the Boulder Dam Recreation Area through a memorandum of agreement with the Bureau of Reclamation (BOR) in 1936. LAKE covers more than 520,000 hectares and is the fourth-largest NPS unit in the contiguous United States. LAKE lies along the northeastern boundary of the Mojave Desert and includes a portion of the high Colorado Plateau on its eastern edge. The recreation area encompasses 229 km of the Colorado River and contains two large reservoirs, Lake Mead and Lake Mojave. The 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 several perennial springs preserve one of the Southwest's most threatened habitats – the desert riparian community. As a result, LAKE hosts populations of many species of special concern. 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 covers almost 620,000 hectares, 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. MOJA includes the densest population of Joshua trees (*Yucca brevifolia*) in the world. Similar to DEVA, the sand dunes of MOJA constitute unique environments that are home to several endemic species. In addition, about half of the land within the preserve has been designated Critical Habitat for the federally-threatened desert tortoise (*Gopherus agassizii*).

Grand Canyon-Parashant National Monument was established in 2000. PARA covers more than 420,000 hectares and is jointly managed by the NPS and Bureau of Land Management (BLM). The monument includes the northeastern boundary of the Mojave Desert and portion of the western Colorado Plateau. Hot desert species are found in the low elevation desert, while cold desert species are found on the higher elevation plateau. The transition zone between these ecosystems is a

distinctive feature that has given rise to elevated biodiversity within PARA. The most prominent topographic feature within the monument is the Shivwits Plateau, which is geographically typical of the Grand Canyon region.

1.2 Overview of Springs

1.2.1 Springs in the MOJN Framework Model

The MOJN I&M Vital Signs Monitoring Plan (Chung-MacCoubrey et al. 2008) presented the MOJN Framework Model, an overarching conceptual model of the ecosystems found in the MOJN parks. At the highest level, the MOJN Framework Model identifies four general systems: the dry system (terrestrial), wet system (aquatic), atmospheric system, and human system, and describes how these systems broadly interact and affect the structure and function of one another.

Although wet systems comprise a small fraction of the landscape within MOJN parks, they are of disproportionate ecological importance. The wet system is defined by areas that have standing or flowing water such as lakes, streams, springs, and wetlands, and are thus able to support vegetation communities that do not rely solely on direct precipitation. These areas have comparably high biodiversity, displaying dense vegetation communities and supporting diverse assemblages of terrestrial and aquatic organisms. Many of the wet systems are isolated relics of formerly connected waterways, and they can support locally endemic species.

The springs portion of the wet systems model is shown in Figure 2. Climate, particularly temperature and precipitation, is the main driver of the groundwater system that maintain springs in the network. Discharge that issues from the groundwater system can either be consumed through evaporation and evapotranspiration by the riparian vegetation around the spring or emerge as surface flow. Stressors that can affect spring ecosystems include climate change, fire, invasive species, groundwater withdrawal, groundwater contamination, diversion, grazing, and other human disturbances.

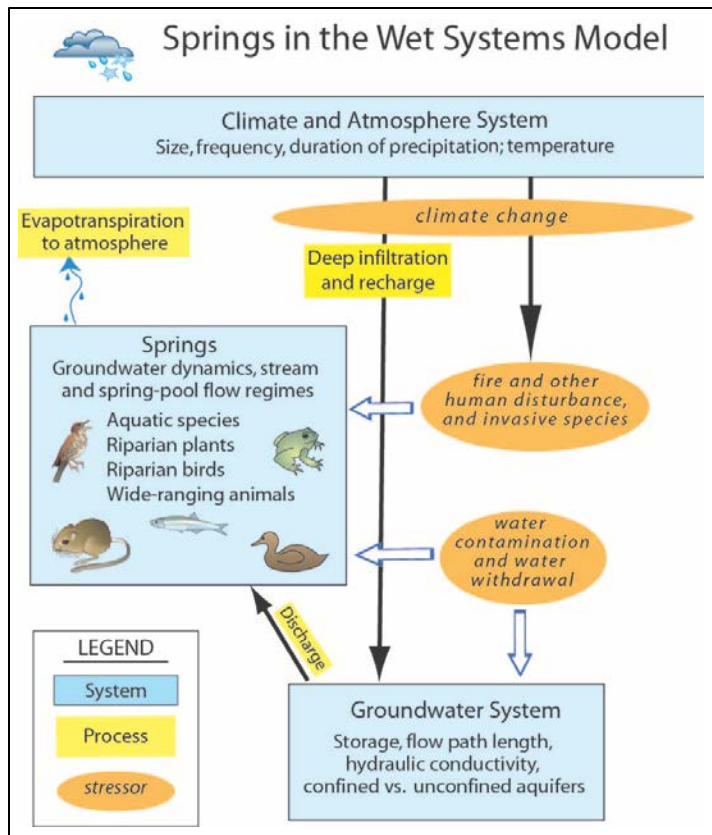


Figure 2. Springs in the wet systems portion of the MOJN Framework Model. Figure modified from Chung-MacCoubrey et al. (2008).

1.2.2 Hydrology of Mojave Desert Springs

Recharge

The water that flows from springs in the Mojave Desert originates from aquifers recharged by rain and snow. Climatic factors, partitioning of precipitation to runoff or infiltration, and spatial linkages of runoff, biotic use, evapotranspiration, and soil hydraulic properties all affect recharge location and rate. In low lying basins, where annual precipitation is low (5-15 cm/yr), rainfall provides moisture to the surface soils but is insufficient to saturate the underlying soils and percolate into the groundwater system (Hevesi et al. 2003, Nishikawa et al. 2004). Groundwater recharge occurs primarily in the mountains and upper piedmont areas where annual precipitation ranges from 15 cm to more than 75 cm (Hevesi et al. 2003) and elevations are greater than 1,500 m (Maxey and Eakin 1950). Where the mountains reach high elevations (e.g., Spring Mountains), winter snowpack provides the dominant source of recharge to the groundwater system. In the southern and lower elevation regions, rainfall is the dominant source of recharge (Nishikawa et al. 2004). Most recharge occurs during the winter and spring, when precipitation is high and evapotranspiration is low.

Aquifers

The aquifers that feed the springs in the Mojave Desert vary greatly in their size and characteristics. Mifflin (1968, 1988) found that springs in the Mojave Desert are fed by aquifers that range in size

from perched basins in mountain ranges, to alluvial aquifers that fill entire valleys, to the Great Basin regional carbonate-rock aquifer system (Harrill and Prudic 1998, Brooks et al. 2014, Belcher et al. 2017) that extends over approximately 240,000 km². In general, smaller aquifers have less discharge, greater seasonal variability in discharge, faster responses to changes in precipitation, and lower water temperatures than larger aquifers. However, these generalizations are not always accurate, and it is common for springs to be fed by a mix of waters from different aquifers.

Discharge

Springs exhibit many different morphologies at the point of discharge, and these morphological characteristics may vary over time. Springer et al. (2008) identified twelve “spheres of discharge”. The six most common spheres of discharge in the MOJN parks are given in Table 2. Aquatic organisms, riparian vegetation, and associated fauna all vary with spring characteristics at the point of discharge. However, spring ecology is greatly influenced by modern and historical human uses as well (e.g., Sada et al. 2005), so spring ecosystems cannot be easily linked to characteristics of the natural flow system.

Table 2. Common spring types in the MOJN parks. Categories taken from Springer et al. (2008).

Spring Type	Description
Exposure	Groundwater is exposed at the surface but does not flow
Helocrene	Groundwater emerges from low gradient cienegas (marshy, wet meadows); often has indistinct or multiple sources
Hillslope	Groundwater emerges from non-vertical hillslopes at 30-60° slopes; often has indistinct or multiple sources
Hypocrene	Groundwater does not reach the surface, typically due to low discharge and high evapotranspiration
Limnocrene	Groundwater emerges into one or more pools
Rheocrene	Flowing spring, groundwater emerges into one or more stream channels

1.2.3 Vegetation Communities at Mojave Desert Springs

Riparian vegetation communities in the Mojave Desert are productive and diverse. For example, more than 75% of terrestrial species, including 80% of birds and 70% of butterflies, are strongly associated with riparian vegetation in the Mojave-Great Basin region (Brussard et al. 1998).

Springs in the Mojave Desert support a range of vegetation communities, from upland vegetation to wetland-obligate species (Figure 3). Cover is dominated by graminoids (e.g., rushes or sedges), trees (e.g., cottonwood), shrubs (e.g., seep willow), or other life forms, or a combination of different life forms. Springs also have unique elements that are difficult to explain and interesting to explore. For example, springs that are near each other and appear to be similar may have very different vegetation communities for reasons that are not easily discerned (e.g., Stevens and Meretsky 2008, Meretsky 2008, Abella et al. 2014). Depending on soil types, location, hydrology, and other factors, plant species richness at a single spring can range from zero to 100 or more (e.g., Cornett 2008).



Figure 3. Examples of spring vegetation communities in MOJN parks. Upper left: Palm Tree Hot Spring, LAKE; invasive tamarisk and algae. Upper right: Winston Basin Spring, MOJA; cattails and shrubs. Lower left: Pocum Cove Upper Spring B, PARA; trees and grasses. Lower right: Cottonball Marsh Sulfur Spring 37, DEVA; no vegetation.

1.2.4 Wildlife at Mojave Desert Springs

Endemic Aquatic Species

The spatial isolation of springs in the Mojave Desert has resulted in the evolution of aquatic-obligate species that are endemic to a single spring or spring province. Endemic species found at springs in the Mojave Desert include mollusks (e.g., Hershler et al. 2014), insects (e.g., Whiteman and Sites 2008), other aquatic invertebrates (e.g., Witt et al. 2006), and fishes (e.g., Fagan et al. 2002). The survival of these species depends on the persistence of perennial water and unimpaired conditions in their very limited habitats.

Amphibians

Frogs, toads, and salamanders can be found at springs in the Mojave Desert. Amphibians require moisture for survival and reproduction, so they are dependent on spring habitats. Some species, such as the Inyo Mountains salamander (*Batrachoseps campi*), are found only at springs on a single mountain range. The relict leopard frog (*Lithobates onca*, formerly *Rana onca*) was once thought to be extinct before being found at eight springs in the Colorado River drainage (Jaeger et al. 2001). Amphibians worldwide are under threat from chytridiomycosis, a disease caused by *Batachochytrium dendrobatidis*, a chytrid non-hyphal zoosporeic fungus (e.g., Wake and Vredenburg 2008). Chytridiomycosis has been observed in red-spotted toad (*Anaxyrus punctatus*) populations in MOJA and JOTR (Gallegos and Fisher 2015).

Native Ungulates

Desert bighorn sheep (*Ovis canadensis nelsoni*) and mule deer (*Odocoileus hemionus*) are present in all of the parks monitored for this protocol, and they require freestanding water to survive. Studies of bighorn sheep in JOTR (Longshore et al. 2009) and mule deer in MOJA (McKee et al. 2015) found that the presence of a reliable water source (i.e., one that is wet year-round) is the most important variable in determining their habitat.

Riparian Birds

The majority of birds in the Mojave Desert depend on wetland and riparian habitats during some phase of their annual cycle. Some species, including the federally-protected southwestern willow flycatcher (*Empidonax traillii extimus*) and least Bell's vireo (*Vireo bellii pusillus*), are riparian-obligates. Degradation and destruction of riparian areas are widely viewed as the most important causes of decline of land bird populations in the Mojave Desert (e.g., Brussard et al. 1998, Tewksbury et al. 2002).

1.3 Threats and Management Concerns

1.3.1 Climate Change

Global climate change has already altered the climate of the southwestern United States (IPCC 2013). In particular, average daily temperatures are increasing (Menne and Williams 2009), heat waves are more frequent (Hoerling et al. 2014), snowpack is reduced (Mote et al. 2005), and snowmelt is occurring earlier in the year (Stewart et al. 2005). The region has also experienced frequent severe droughts since 2001 (MacDonald 2010).

An NPS study compared recent climate data from a number of parks with the historical record (Monahan and Fisichelli 2014), including six MOJN parks: 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 there were fewer frost days than in any other period. Precipitation results were less unequivocal (the 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 more resilient to changes in surface water hydrology, as they respond slowly to changes in recharge rates. However, springs fed in whole or in part by small, local aquifers are vulnerable to drought, with changes ranging from lower discharges and reduced aquatic habitat to seasonal or year-round drying. At all springs, higher air temperatures can lead to increases in water consumption by existing vegetation, changes in vegetative communities, and changes in patterns of wildlife use.

1.3.2 Groundwater Withdrawal

In many cases, aquifers that are the source of water to springs are viewed as potential targets for groundwater extraction. If the human population in the Southwest 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 higher demand and use of groundwater resources for municipal, agricultural, and industrial water supplies.

Large-scale groundwater withdrawals create cones of depression in the water table, which can lower the water level at springs, reducing or eliminating discharge. This can result in major changes to spring ecosystems (Patten et al. 2008) and potentially 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).

1.3.3 Diversion

It is common for the flow of desert springs to be diverted at or near the source, typically to provide water for cattle, mining operations, human consumption, or other purposes. In some cases, the entire flow of the spring is diverted into a tank or pipeline, and the spring ecosystem is eliminated. In other cases, the riparian area below the point of diversion can be greatly reduced or eliminated (Unmack and Minckley 2008). Both active and historical diversions are widespread at springs in the network.

1.3.4 Recreation

Desert springs are attractive sites for park visitors because they provide water and vegetation in the otherwise arid landscape. Improper uses of springs by visitors include social trails, fire pits, bank degradation, and failure to dispose of garbage and human waste. Other concerns include the alteration of natural habitats by the creation of bathing pools as well as the enhanced spread of invasive plants and animals from spring to spring (e.g., Shepard 1993, BLM 2013).

1.3.5 Grazing

Numerous studies have found that grazing by cattle (e.g., Fleischner 1994) and feral equines (e.g., Beever and Brussard 2000) has a negative impact on riparian vegetation at springs. Habitat alteration

due to grazing can threaten endemic springsnail populations (Hershler et al. 2014). Ostermann-Kelm et al. (2008) found that bighorn sheep avoid water sources when feral horses are present.

Conversely, grazing at springs prevents open pools from growing over with vegetation and filling with sediment (Marty 2015), thus preserving habitat for amphibians (Bradford et al. 2004) and fishes (Kodric-Brown and Brown 2007). Managing grazing at springs is not, therefore, a simple matter of building exclosures at every site, but instead requires the careful consideration of several possible effects.

1.3.6 Invasive Species

In addition to feral livestock, invasive fauna at springs in the Mojave Desert include amphibians (e.g., American bullfrog [*Lithobates catesbeianus*]), fish (e.g., mosquitofish [*Gambusia affinis*]), arthropods (e.g., red swamp crayfish [*Procambarus clarkia*]), and molluscs (e.g., Malaysian trumpet snail [*Melanoides tuberculata*]). These invasive species can have a negative effect on native fauna through competition for resources (e.g., Chen et al. 2013), predation (e.g., Phillips et al. 2010), or hybridization (e.g., Galicia et al. 2015).

Common invasive plants found at springs in the Mojave Desert include tamarisk (*Tamarix ramosissima*), non-native grasses (e.g., *Schismus barbatus*), date palms (*Phoenix dactylifera*), and watercress (*Rorippa nasturtium-aquaticum*). These invasive species can have direct effects on native plants, such as outcompeting them for space and nutrients, which alter vegetation communities at springs. Invasive plants also have indirect effects at springs, such as invasive brome species shifting fire regimes (Brooks et al. 2004) and altering soil nutrient availability (Evans et al. 2001).

Both direct and indirect effects of invasive species can provoke cascading changes to desert springs. In DEVA, for example, springs colonized by invasive palms contained one-sixth of the arthropod abundance, one-third of the species richness, and half the family richness compared to springs without invasive palms (Holmquist et al. 2011). Additionally, invasive plants like tamarisk change vegetation structure and composition in plant communities, which can in turn affect avian populations (Fleishman et al. 2003).

1.4 Objectives

The intent of the NPS I&M Program is to monitor natural resource “vital signs,” including those for water resources (Chung-MacCoubrey et al. 2008). Vital signs are defined as a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, the known or hypothesized effects of stressors, or elements that have important human values or other resource significance. The selection of vital signs for monitoring in the MOJN parks was a multi-year, multi-agency collaborative process. The vital signs monitored by the MOJN I&M Desert Springs protocol are surface water dynamics and surface water chemistry, where water availability and water quality are the indicators used to report on the condition of these two vital signs.

1.4.1 Monitoring Questions

Monitoring questions were developed by MOJN I&M staff, in consultation with MOJN park managers, to guide the development of the most important monitoring objectives for the MOJN I&M Desert Springs protocol, which are the surface water dynamics and surface water chemistry vital signs. This protocol was designed to address two monitoring questions:

- Is water availability at a subsample of springs in the five monitored parks changing over time?
- Is water quality at a subsample of springs in the five monitored parks changing over time?

1.4.2 Measurable Objectives

The MOJN I&M Desert Springs protocol investigates the monitoring questions posed above by collecting data to address the following measurable (quantitative) objectives:

- Determine the status and trends of water availability at a subsample of springs in each of the five monitored parks.
- Determine the status and trends of water quality at a subsample of springs in each of the five monitored parks.

1.4.3 Qualitative Measurements

In addition to the measurable objectives, this protocol will also collect qualitative measurements of additional site condition information. These qualitative measurements include:

- Dominant vegetation
- Invasive plants
- Disturbance
- Repeat Photographs

Because MOJN I&M staff will often be the only NPS staff visiting desert springs regularly, these qualitative measurements will provide park managers with site condition information that would not be collected otherwise. Although these qualitative measurements cannot be statistically analyzed for status and trends at this time, they still provide important site condition information that park managers can use to assess the health of springs. Table 3 summarizes all measurements that will be collected for the protocol.

Table 3. Summary of the quantitative and qualitative measurements collected for the MOJN I&M Desert Springs protocol.

Measurement Type	Measurable Objectives	
Quantitative	Water Availability (Discrete)	Flow condition (presence or absence of surface water)
	Water Availability (Discrete)	Discharge (flow rate of surface water)
	Water Availability (Discrete)	Surface water dimensions (length and width of surface water)
	Water Availability (Continuous)	Record of wet / dry cycle (data-logging sensors)
	Water Quality	“Core” parameters (temperature, pH, specific conductance, and dissolved oxygen)
Qualitative	Dominant Vegetation	Ranking of vegetation life forms within spring area
	Invasive Plants	List of invasive plants found within spring area
	Wildlife Use	List and description of wildlife evidence within spring area
	Disturbance	Index of natural and anthropogenic disturbances within spring area
	Repeat Photographs	Visual documentation of spring source, upstream, and downstream

1.4.4 Integration with Other Monitoring Protocols and Resource Management Efforts

Since desert springs are a salient feature of MOJN parks, the network has developed several protocols to monitor different aspects of these springs. In particular, this protocol complements the MOJN I&M Selected Large Springs protocol (Moret et al. 2016), which intensively monitors water quantity, water quality, water chemistry, and benthic macroinvertebrates at twelve high-priority springs across five MOJN parks. These twelve springs were chosen by park managers for their hydrological permanence and ecological importance, so they are not representative of the springs monitored for the MOJN I&M Desert Springs protocol.

Nevertheless, data collected for the two protocols could be combined to present a fuller picture of surface water availability across the landscape. For instance, Fortynine Palms Oasis in JOTR is an important water source for bighorn sheep in the summer months when many of the smaller springs run dry (Longshore et al. 2009). Therefore, any assessment of bighorn habitat would include both water availability data collected at smaller springs across the park for the MOJN I&M Desert Springs protocol as well as water quantity data collected at Fortynine Palms Oasis for the MOJN I&M Selected Large Springs protocol.

MOJN I&M is also developing a Spring Vegetation protocol (Hupp et al. *in review*) that intensively monitors plant communities at eighteen high-priority springs across five MOJN parks, including most of the springs monitored by the MOJN I&M Selected Large Springs protocol and four springs monitored by the MOJN I&M Desert Springs protocol. These eighteen springs were chosen in collaboration with park managers and are not representative of typical desert springs.

Vegetation communities at desert springs have high species richness and are variable temporally (within a growing season and across years) and spatially (within a spring and across springs). Because of this variability, the MOJN I&M Spring Vegetation protocol conducts thorough and methodical sampling every three years in order to adequately address the measurable objectives on a reasonable timescale. To monitor all springs in the MOJN I&M Desert Spring protocol at this level of detail would be prohibitively resource intensive. Consequently, while the MOJN I&M Spring Vegetation protocol monitors the status and trends of vegetation communities by collecting rigorous and quantitative plant data with species-level identification, the MOJN I&M Desert Springs protocol provides context on site condition by conducting rapid and qualitative assessments of vegetation lifeforms.

Despite these differences, there are opportunities for the two protocols to complement each other. For instance, if a particular plant species becomes less abundant at one of the intensively-monitored springs, MOJN I&M Desert Springs protocol data could be reviewed to determine if that species is located elsewhere for further investigation. Conversely, if MOJN I&M Desert Springs protocol data indicate that a particular invasive plant is being detected at new locations, then MOJN I&M Spring Vegetation protocol data could be reviewed to determine which habitats the invasive plant is colonizing, which native plants it is displacing, and how fast it is increasing in abundance.

The MOJN I&M Invasive Plant Species Early Detection (IPSED) plan (Hupp et al. 2017) describes several tiers of monitoring that can be employed to detect targeted invasive plants that have not yet become fully established in the MOJN parks. MOJN I&M Desert Springs field crews will collect invasive plant data at springs following the IPSED plan, freeing the parks to focus on other areas. MOJN I&M Desert Springs protocol invasive plant data will be fully integrated with IPSED data for the purposes of alerting park managers to problems. Importantly, all invasive plant data collected in the MOJN I&M Desert Spring protocol is intended to inform park managers. Invasive plants will not be tracked over time, since this would require a higher level of skill and training than is feasible for most field crews. In other words, invasive plant data collected for this protocol will not be used to monitor the status and trends of invasive plants at desert springs.

Following the IPSED guidelines, invasive plant data collected for this protocol will also be reported to the Lake Mead Exotic Plant Management Team (EPMT), which treats exotic plant invasions throughout the Southwest. Invasive plant data will be entered into the National Invasive Species Information Management System (NISIMS), which is the database used to record plant presence and treatment by the EPMT. In this way, monitoring by the MOJN I&M Desert Springs protocol will serve both to alert the EPMT to new invasions and to track the long-term effects of treatment after the EPMT has visited a site.

We anticipate that additional site condition information collected for the MOJN I&M Desert Springs protocol will be used by park managers to make decisions regarding water management, grazing, and other issues. As such, these qualitative measurements will be important for managing natural resources, even though long-term trend analysis of the data will not occur at this time. MOJN I&M will work with network parks to ensure that such collaborations are productive.

2. Sampling Design

2.1 Target Population

Many of the desert springs included in the database are located in the same drainage and close together (e.g., Figure 4). These springs can generally be thought of as different outlets of the same spring group. In most cases, one spring in the group, referred to as the “representative spring” by Dekker and Hughson (2014), has the greatest flow, the largest area of riparian vegetation, and is the least susceptible to drying (e.g., Salt Spring in Figure 4). The target population for this protocol is the population of representative springs.

One of the benefits of this choice is that it eliminates the effect of subjective choices made by field crews during the inventory. In areas of diffuse discharge, it may be difficult to distinguish individual outlets. For example, the DEVA inventory includes 24 outlets of Gnome Spring as individual springs, but the large complex of seeps at Nevares Spring is included as a single entry. Working with a single representative spring eliminates this subjectivity.

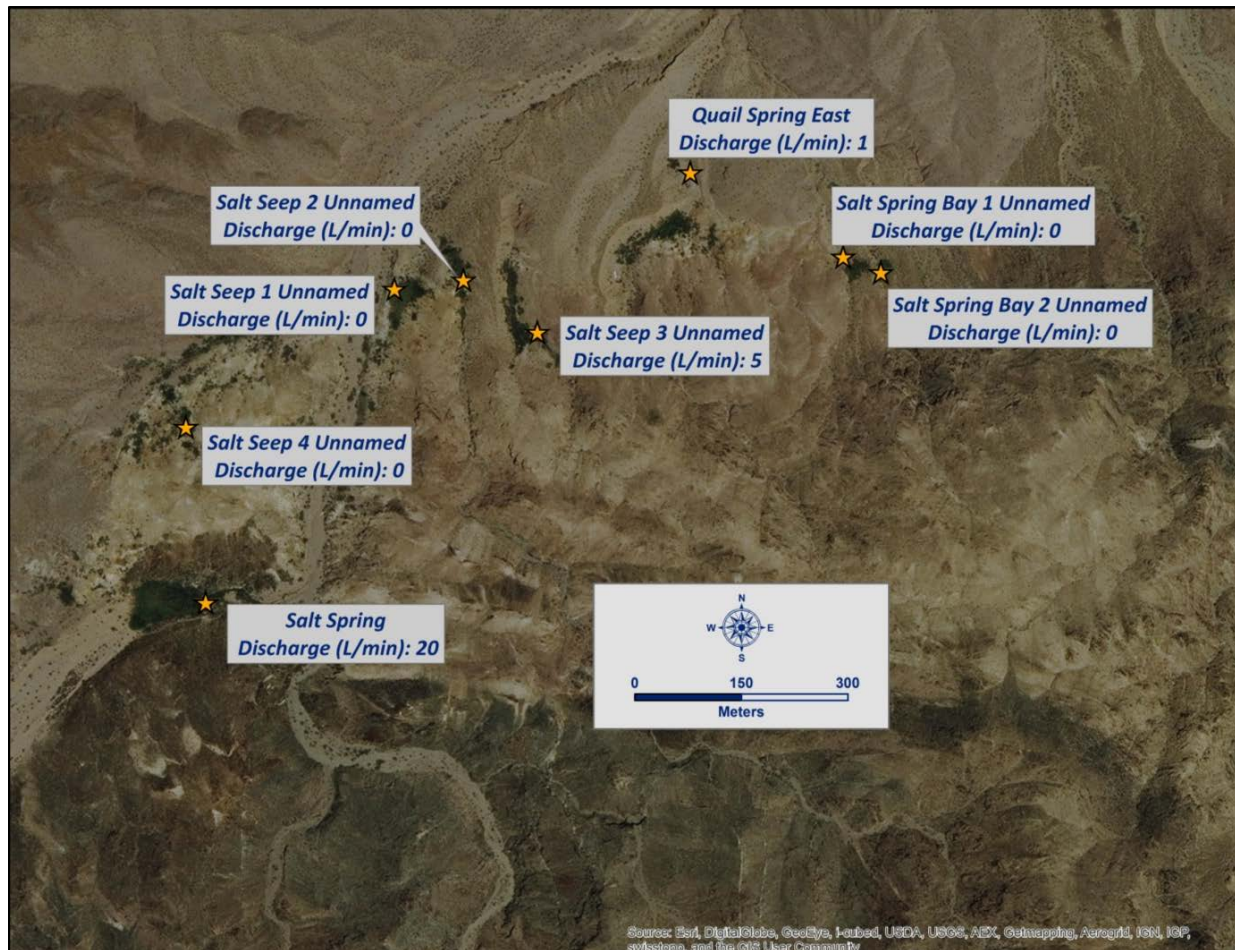


Figure 4. Springs in the vicinity of Salt Spring in LAKE. Background is 2013 NAIP imagery provided by U.S. Department of Agriculture Farm Services Agency.

2.2 Sample Frame

The sample frame for the MOJN I&M Desert Springs protocol is derived from the spring inventories conducted in DEVA (Sada and Pohlmann 2007), JOTR (Sada and Jacobs 2008b), LAKE (Sada and Jacobs 2008c), MOJA (Poff et al. 2012), and PARA (Sada and Jacobs 2008a). The database that combines these inventories contains 1,868 entries (Table 4). Many of these entries, however, were for wells or tinajas or were records of locations visited by the crews where no spring was found. We removed these records from the sample frame, leaving 1,399 springs.

Table 4. Number of inventory locations, springs, representative springs, and springs in the sample frame for each park.

Park	Number of Locations in Spring Inventory	Number of Springs	Number of Representative Springs	Number of Springs in Desert Springs Protocol Sample Frame
DEVA	1,027	814	237	230
JOTR	293	87	51	48
LAKE	89	86	52	44 (15 in Black Canyon)
MOJA	238	215	115	100
PARA	221	197	76	66
All Parks	1,868	1,399	531	487

Following the procedures described by Dekker and Hughson (2014), we reviewed field notes, inventory data, aerial imagery, and topography to identify spring groups and determine the representative spring for each group (springs that are not part of a group are also considered representative springs). This review identified 531 representative springs.

Of the 531 representative springs, 44 were not included in the MOJN I&M Desert Springs protocol sample frame: 26 are not located on park land, 12 are monitored by MOJN as part of the Selected Large Springs protocol, three are heavily-used recreational hot springs, and three are periodically inundated by water released from the Hoover Dam. The resulting sample frame consists of 487 springs in the five parks (Table 4).

2.3 Spatial and Revisit Design

2.3.1 Rotating Panel

MOJN I&M Desert Springs field crews can reliably visit 120 springs over the course of a six-month field season. The allocation of these springs among parks and years (the panel design) was chosen based on three objectives:

1. Include a sufficient number of springs to provide meaningful information on the status of springs in each park.
2. Visit a smaller number of springs annually to detect the effects of particularly wet and dry years on springs in the following years and to retrieve data-logging sensors (Chapter 3).
3. Monitor springs frequently enough to provide timely information to park managers.

MOJN I&M has chosen a rotating panel design, in which some springs are visited every year and some are visited every three years (a [1-0,1-2] panel in the notation described by Chung-MacCoubrey and others (2008)). As Table 5 shows, 60 springs (20 springs in DEVA and 10 springs in each of JOTR, LAKE, MOJA, and PARA) will be visited each year. The remaining 60 springs visited each year will be rotated among the parks on a three year cycle, with more spring visits allocated to parks with larger spring populations. The total sample size over the three years is 234 springs, with 80 springs in DEVA, 35 springs in JOTR, 29 springs in LAKE (as discussed below), 45 springs in MOJA, and 45 springs in PARA.

Table 5. Total number of springs visited per park per year.

Year	DEVA	JOTR	LAKE	MOJA	PARA
2016-17	20	35	10	10	45
2017-18	80	10	10	10	10
2018-19	20	10	29*	45	10
2019-20	20	35	10	10	45
2020-21	80	10	10	10	10
2021-22	20	10	29*	45	10

*As discussed below, LAKE crews may monitor an additional 15 springs in Black Canyon every 3rd year.

The ability of the sample sizes in each park to provide meaningful information on the status of springs (Objective 1, above) can be evaluated using the Clopper-Pearson approach to confidence limits for the hypergeometric distribution (Clopper and Pearson 1934). For each park, we know the number of springs in the sample frame, so we can test the uncertainty resulting from a given result for a given sample size. Consider a scenario in which 25% of the monitored springs in each park are dry. As shown in Figure 5, the rotating panel design used in this protocol can provide estimates of the proportion of dry springs with a 95% uncertainty range of approximately plus or minus 10% for all parks every third year.

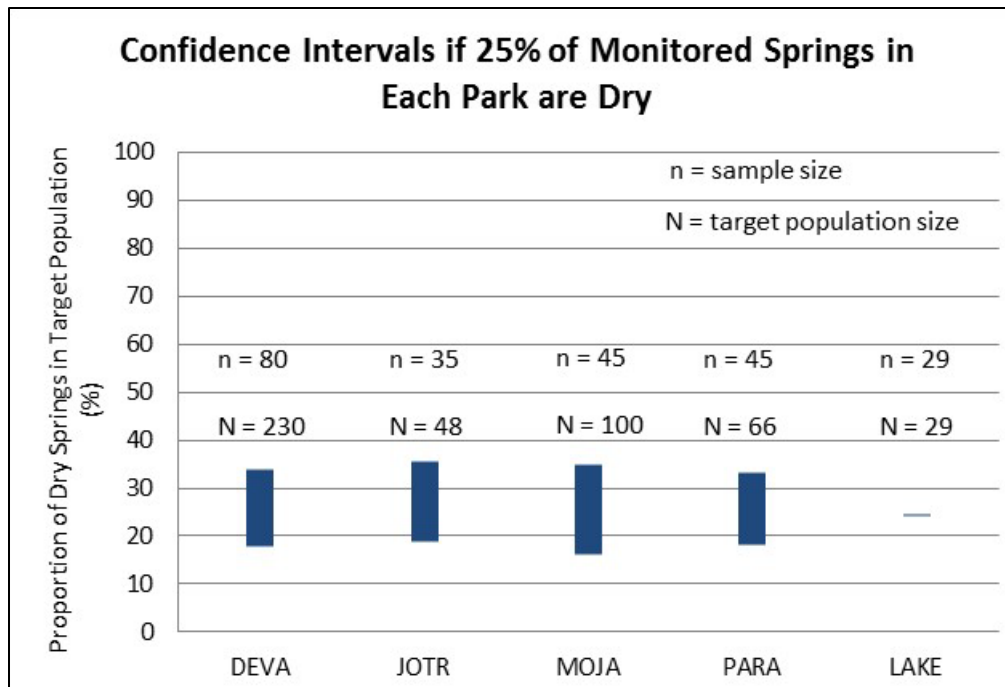


Figure 5. Confidence intervals for each park estimate of proportion of dry springs in the target population in a hypothetical situation where 25% of springs in the sample are found to be dry. The proportion of dry springs in LAKE is known exactly because 100% of the target population is sampled.

2.3.2 Spring Selection

Monitored springs were selected using the Generalized Random Tessellation Stratified (GRTS) algorithm (Stevens and Olson 2004). GRTS is widely used in ecological monitoring to draw spatially-balanced random samples (e.g. Miller et al. 2011, Olsen et al. 2012). Because none of the measurable objectives addressed by the protocol call for stratification, the GRTS draws for each park used equal selection probabilities. In other words, where the population for each park was all of the springs in its sample frame (Table 4), the sample was drawn at random from this entire population. Populations were not separated into strata, such as geographic regions or watersheds, and samples were not drawn from within these strata. Monitored springs that were selected using GRTS were assigned a specific GRTS number, and that numerical order must be followed to maintain the spatial balance of the sample.

The GRTS draws were conducted in the statistical platform R using the package Sdraw (Starcevich et al. 2016), and all springs were selected within Sdraw using a uniform selection probability. Beyond the initial number of springs planned for annual and three-year monitoring, the remaining springs in the population for each park were included in the GRTS draw as the “oversample.” Oversample springs can be added to the rotating panel if any of the original springs in the sample prove to be unusable (e.g., unsafe or inaccessible) or if the protocol is expanded to include more springs in the future. To ensure statistical validity and spatial balance, oversample springs must be incorporated into the sample *in the order in which* they appear in Appendix A. For example, the spring at GRTS number 100 must be included in the sample before the spring at GRTS number 105.

The GRTS draws for the five parks are mapped in Figures 6-10 and listed in Appendix A. For spring groups, the location in Appendix A is the representative spring, which is the location that should be monitored. Oversample springs are also listed in Appendix A. For most parks, the GRTS draw can be understood by viewing the maps; however, LAKE is more complicated and is explained below.

LAKE GRTS Draw

Fifteen of the springs in the LAKE sample frame are located in Black Canyon, the area below the Hoover Dam (Figure 6). These springs are fed by water from Lake Mead and a combination of other local and regional sources (Moran et al. 2015). Many of these springs are also popular sites for park visitors, who access them by hiking, kayaking, or taking a river tour. During the pilot study, 100% of the sensors placed in Canyon springs were lost, presumably due to scouring by rain events or disturbance by visitors. Due to the high rate of sensor loss, the necessity of boat access, and the proximity of these springs to an alternative and permanent source of water for wildlife, we have chosen to regard these springs as a separate subpopulation.

MOJN I&M field crews will visit 10 of the springs located outside Black Canyon each year, with these 10 springs chosen using a GRTS draw from the population of 29 springs outside Black Canyon. Every third year, MOJN I&M field crews will visit the remaining 19 springs in the GRTS draw, and the Protocol Lead will train LAKE Natural Resource personnel to monitor the 15 springs in Black Canyon. This approach uses the experience and expertise of LAKE personnel in boat operations, while maintaining the statistical validity of the protocol in the event that boat access is not available.

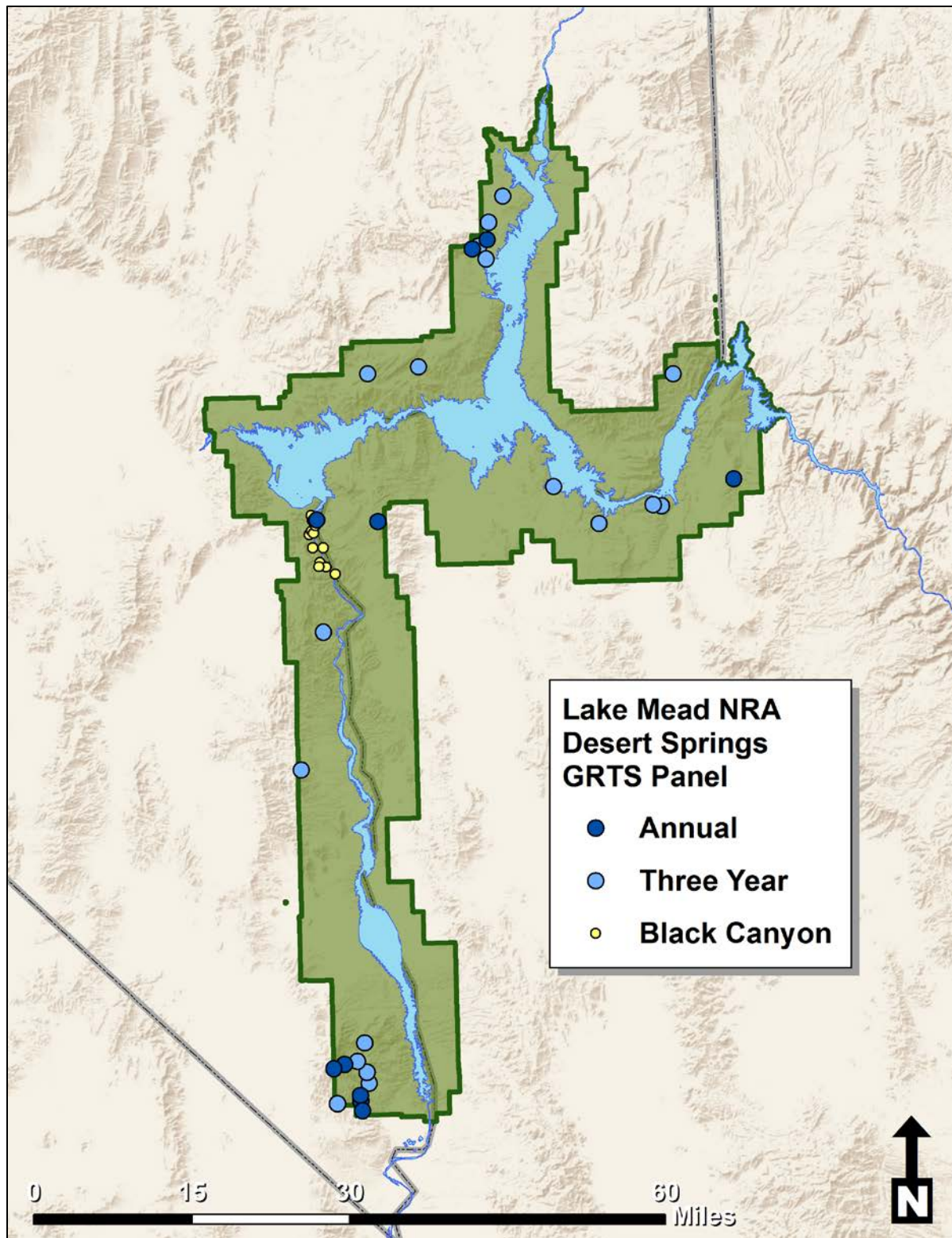


Figure 6. Map of the springs monitored in LAKE. Dark blue circles indicate springs visited annually where data-logging sensors will be deployed. Light blue circles indicate springs visited every three years. Small yellow circles indicate springs in Black Canyon that may also be visited every three years or opportunistically as boat access and staffing are available.

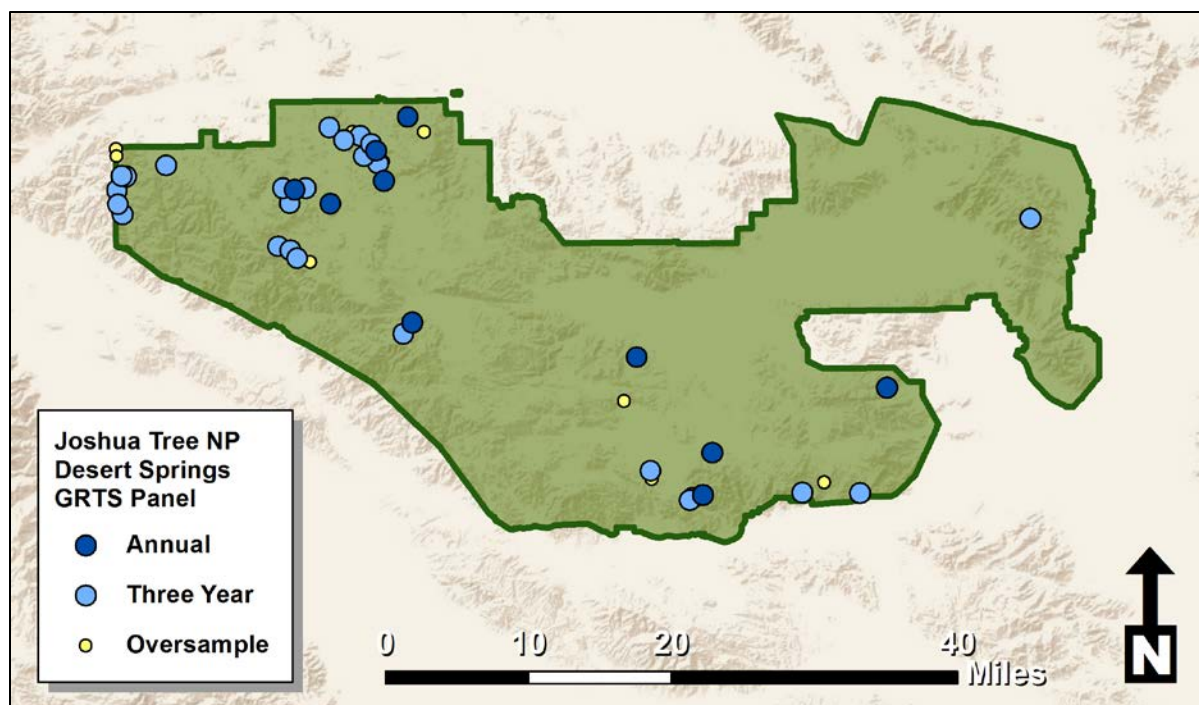


Figure 7. Map of the springs monitored in JOTR. Dark blue circles indicate springs visited annually where data-logging sensors will be deployed. Light blue circles indicate springs visited every three years. Small yellow circles indicate the remaining oversample springs in the population.

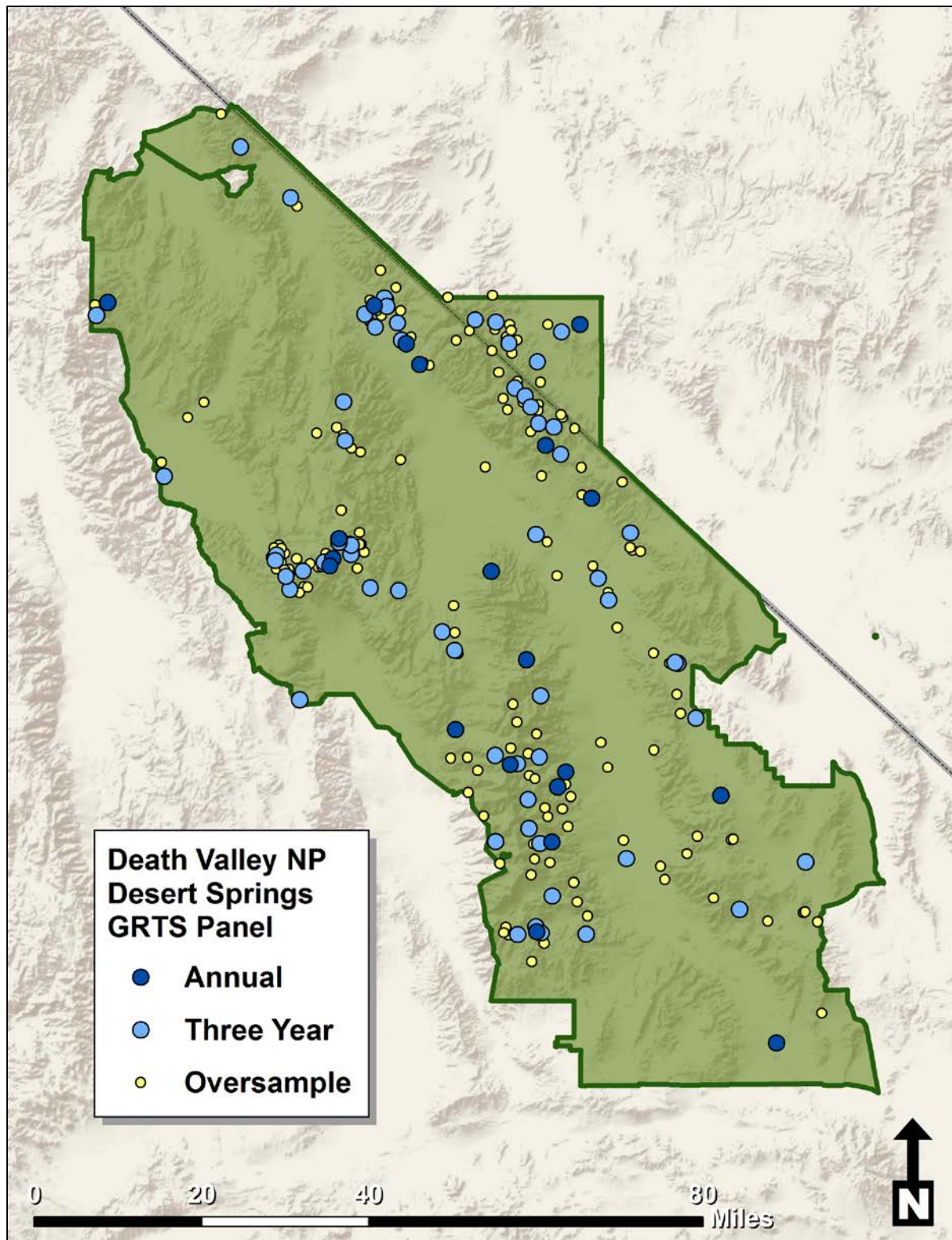


Figure 8. Map of the springs monitored in DEVA. Dark blue circles indicate springs visited annually where data-logging sensors will be deployed. Light blue circles indicate springs visited every three years. Small yellow circles indicate the remaining oversample springs in the population.

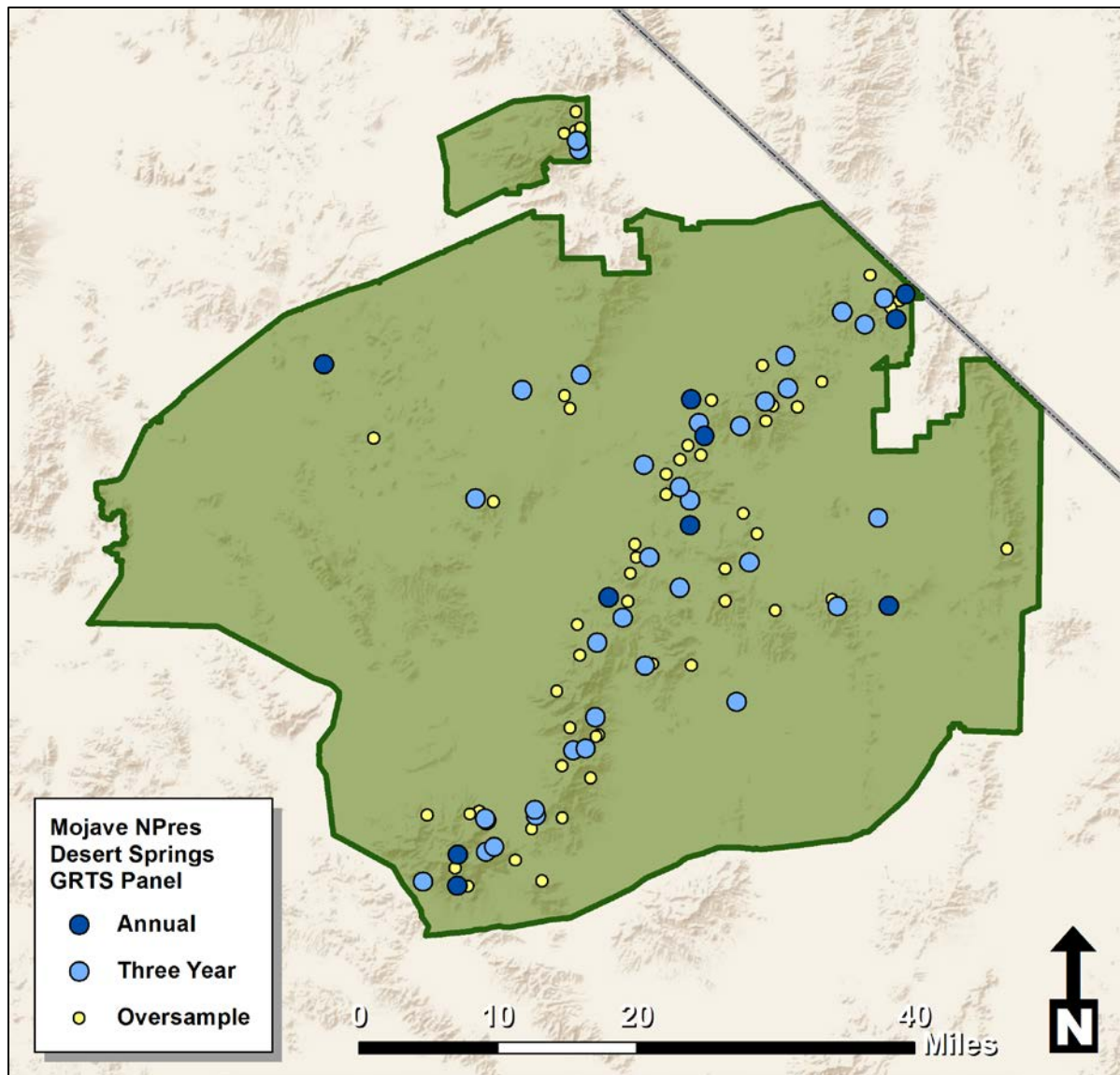


Figure 9. Map of the springs monitored in MOJA. Dark blue circles indicate springs visited annually where data-logging sensors will be deployed. Light blue circles indicate springs visited every three years. Small yellow circles indicate the remaining oversample springs in the population.

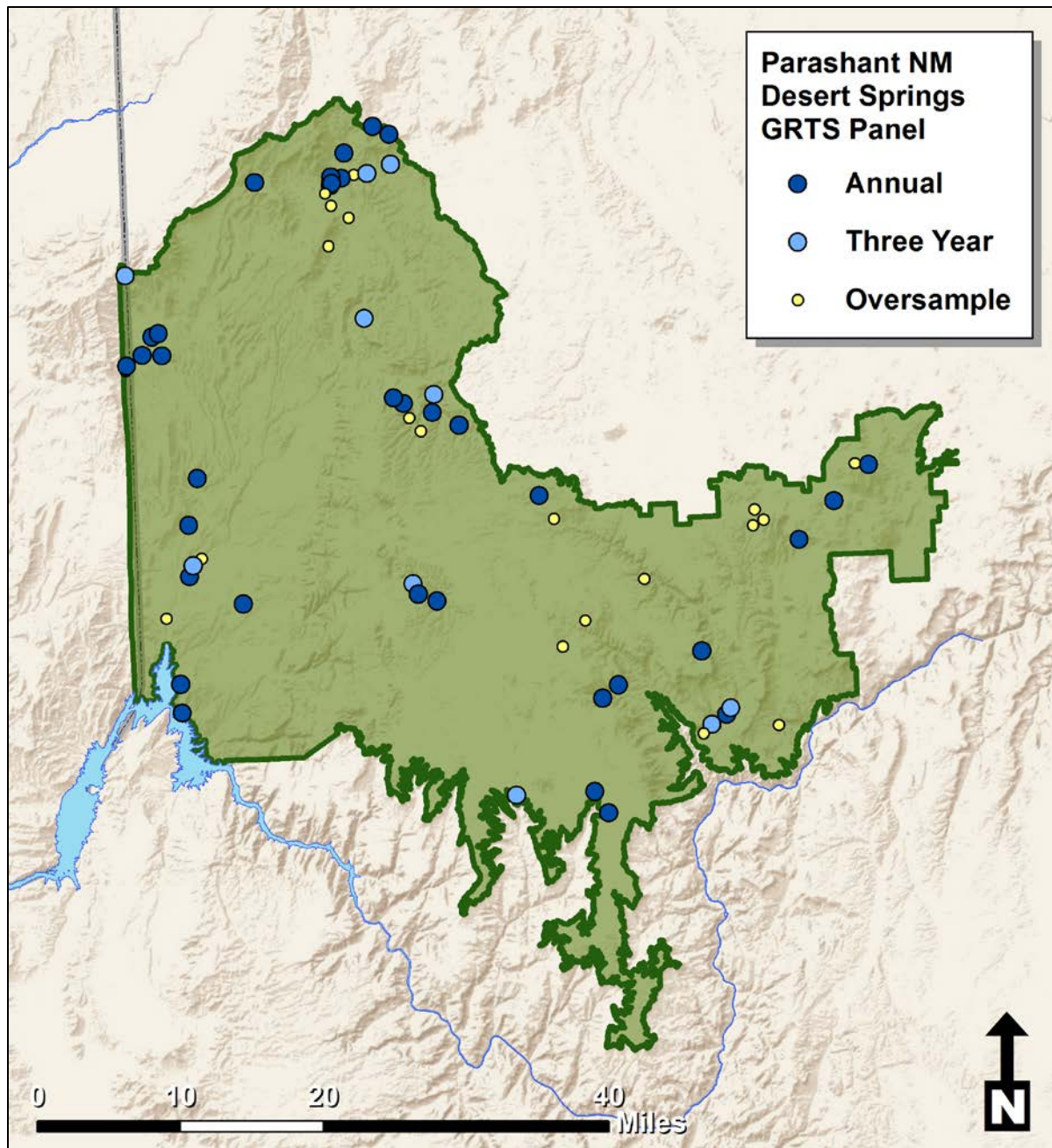


Figure 10. Map of the springs monitored in PARA. Dark blue circles indicate springs visited annually where data-logging sensors will be deployed. Light blue circles indicate springs visited every three years. Small yellow circles indicate the remaining oversample springs in the population.

2.3.3 Design Flexibility

One of the primary benefits of this sampling design is its flexibility. The annually-visited springs and the triennially-visited springs are part of the same GRTS draw, so data from the two sets of springs can be analyzed together. If more field crew time or personnel are available, then springs from the rotating panel can be added to the annual sample, or springs from the over-sample can be added to the rotating panel. If less field crew time or personnel are available, then springs from the annual

sample can be moved to the rotating panel, or springs can be dropped from the rotating panel. As long as the monitored springs are taken in order from the GRTS draw, the statistical integrity of the protocol will be intact.

2.4 Power Analysis

A power analysis is a statistical tool for assessing the performance of a trend test so that a proposed monitoring plan may be evaluated before implementation (e.g., Sims et al. 2006). Statistical power describes the probability that a hypothesis test will reject the null hypothesis when the alternative hypothesis is true (i.e. detect a change when there actually is a change; Cohen 1988). In monitoring, power describes the ability of a trend test to detect a true change in a parameter of interest. Monte Carlo simulations are used to determine how *quickly* the proposed 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 developing a monitoring plan. More simply stated, power analyses and Monte Carlo simulations allow us to estimate the sample size needed and the frequency at which plots should be revisited.

L. A. Starcevich conducted power analyses using observations made at springs in DEVA and LAKE from 2005 to 2006 (Sada and Pohlmann 2007, Sada and Jacobs 2008c) and from 2011 to 2013 (MOJN I&M pilot study) as well as observations on the presence and absence of water at springs in MOJA from 2004 to 2012 (Dekker and Hughson 2014). These data (Figure 11) were used in the power analyses and Monte Carlo simulations based on their sample sizes and the length of the records. The full power analysis report is presented in Appendix B. The methods and results are summarized here.

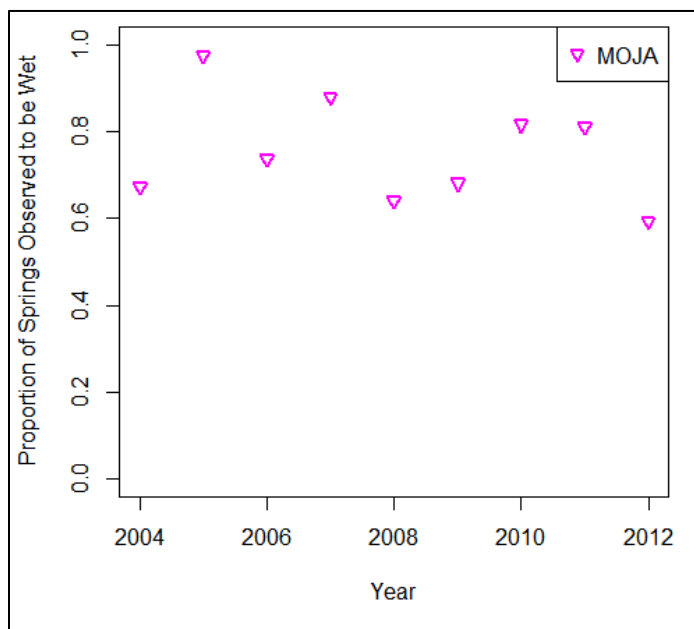


Figure 11. Data used for the power analyses. Proportion of MOJA springs where water was observed.

2.4.1 Methods

Mean values and variance parameters were calculated from the MOJA spring permanence data (measured as the presence or absence of water at a spring). These statistical parameters were then used in Monte Carlo simulations to generate random samples of simulated data with a known simulated trend. Trends were modeled as proportional increases or decreases. For example, if surface water were present at 80% of springs visited in a given year, and the annual trend was a 2% decrease, then surface water would be present at 72% of springs five years later. The sample design described above in section 2.3 was used to simulate the data sets.

“Trend scenarios” were developed to analyze a range of potential monitoring periods and annual trends (see Table 7). For each scenario, trend tests were conducted for 1,000 simulated data sets using generalized linear mixed models (GLMM; binomial family). Trend tests were conducted at the $\alpha = 0.10$ level (that is, a 90% confidence interval).

The random effects in the GLMM include a spring-level intercept, a spring-level slope, and a year-level intercept. These random effects provide a mechanism for partitioning the total variation into variance components. The spring-level random intercept characterizes the variation in the outcome among springs. The spring-level random slope effect measures the variation among the trend lines at each spring. The year-level intercept describes the variation in the outcome among years. These random effects provide greater understanding of the sources of variation and a measure for selecting which indicators may be more useful for long-term monitoring. The variation among spring-level slopes and the variation among years both greatly impact the power to detect trend. Values of each variance component may be relatively small compared to the spring-level variation but may still exact a prohibitively large toll on the power to detect trend (Starcevich et al. 2018, Urquhart and Kincaid 1999).

2.4.2 Results

Trend Analysis

No conclusive evidence of a trend was observed for the presence of water at springs in MOJA ($z = -1.615$, $p\text{-value} = 0.1060$).

Test Size

Test size is measured as the proportion of times in which a trend was detected when no trend was simulated (i.e., the null hypothesis was incorrectly rejected, or a Type I error). For a trend test conducted at the $\alpha = 0.10$ level, test size is expected to be 0.10. Table 6 shows the test sizes for Monte Carlo simulations of monitoring conducted over 12, 18, 24, and 30 years. The trend tests indicate a trend in simulated wet / dry data when none exists more frequently than expected. The high test size is likely due to the high level of year-to-year variability in the wet / dry data.

Table 6. Trend test size for power analyses of wet / dry data. Tests conducted at $\alpha = 0.10$.

Monitoring Period (Years)	Wet / Dry (MOJA)
12	0.165
18	0.154
24	0.140
30	0.132

Test Power

Test power is calculated as the proportion of times in which a trend was detected when a non-zero trend was simulated (i.e. the null hypothesis was correctly rejected). Table 7 provides the power approximation for monitoring periods of 12, 18, 24, and 30 years and for annual trends of 2%, 4%, and 6%. For annual trends of 4% to 6%, the power analysis indicates that trend power of at least 0.80 may be obtained within 30 years with proposed sample sizes. An annual 2% trend may be detected in spring permanence at MOJA within 30 years.

Table 7. Power to detect trends at the 0.10 level for different trend scenarios of spring permanence at MOJA.

Outcome	Monitoring Period (Years)	2% Annual Trend	4% Annual Trend	6% Annual Trend
Presence of Water at Springs (MOJA)	12	0.440	0.693	0.735
	18	0.680	0.788	0.860
	24	0.765	0.913	0.943
	30	0.850	0.974	0.969

2.5 Response Design

The response design for the MOJN I&M protocol is intended to meet two objectives:

- Collected data should address the monitoring objectives for the protocol.
- Field crews should be able to complete all of the measurements and observations at a spring in one hour or less. This constraint is necessary to achieve the sample size needed to make meaningful statistical inferences.

MOJN I&M has worked with other I&M networks in the Southwest (Chihuahuan Desert Network, Northern Colorado Plateau Network, Sonoran Desert Network, and Southern Colorado Plateau Network) to standardize how certain measurements and observations are made. The response variables described below are drawn from the work of Data Managers and Protocol Leads at these networks, as well as staff from the Inventory and Monitoring Division at the Washington Support Office in Fort Collins, Colorado. In addition, the methods used by this protocol drew from those developed by Donald Sada and Karl Pohlmann of the Desert Research Institute, particularly their Level I inventory method (Sada and Pohlmann 2006).

2.5.1 Spring Acceptance and Classification (SOP 4)

Field crews must first decide whether to accept or reject a spring for monitoring. Springs may be rejected for reasons of inaccessibility, unsafe conditions, or threats to sensitive natural or cultural resources. Field crews then classify each spring based on the “sphere of discharge” categories developed by Springer et al. (2008). Common spheres of discharge at springs monitored for this protocol include rheocrene, limnocrene, hypocrene, helocrene, and hillslope.

2.5.2 Water Availability: Flow Condition (SOP 5)

Surface water availability is monitored by assessing the flow condition at a spring. The six categories of flow condition are dry, wet soil, standing water, flowing water, flood, and frozen. If possible, field crews will measure discharge at springs with flowing water using the volumetric method, which Turnipseed and Sauer (2010) describe as “the most accurate method of measuring small discharges.” When discharge is too low or too high to use the volumetric method, field crews will visually estimate discharge. Visual estimates cannot be used in quantitative analyses, but can provide some information to park managers regarding conditions at the spring. Field crews will also record surface water dimensions of length and width.

2.5.3 Water Availability: Data-Logging Sensors (SOP 6)

Data-logging sensors provide continuous records of the seasonal presence of surface water at a smaller number of annual springs in each park (refer to the section on Sample Design). Sensors are bolted into the substrate near the spring source or else tied to a rock or sturdy branch to prevent loss by flood events or wildlife. Field crews retrieve old sensors and deploy new sensors at each annual visit. The sensors automatically collect temperature and humidity data every four hours, which can be downloaded in the office (Figure 12).

Field tests conducted during the pilot season showed that the sensors record a humidity below 80% when no surface water is present and above 80% when the sensor is submerged in water or resting on saturated ground. The humidity records can therefore be converted into records of the wet / dry cycle at springs using an 80% cutoff. These records can provide information about the seasonal availability of water to wildlife as well as the response of spring hydrology to long-term changes in climate.

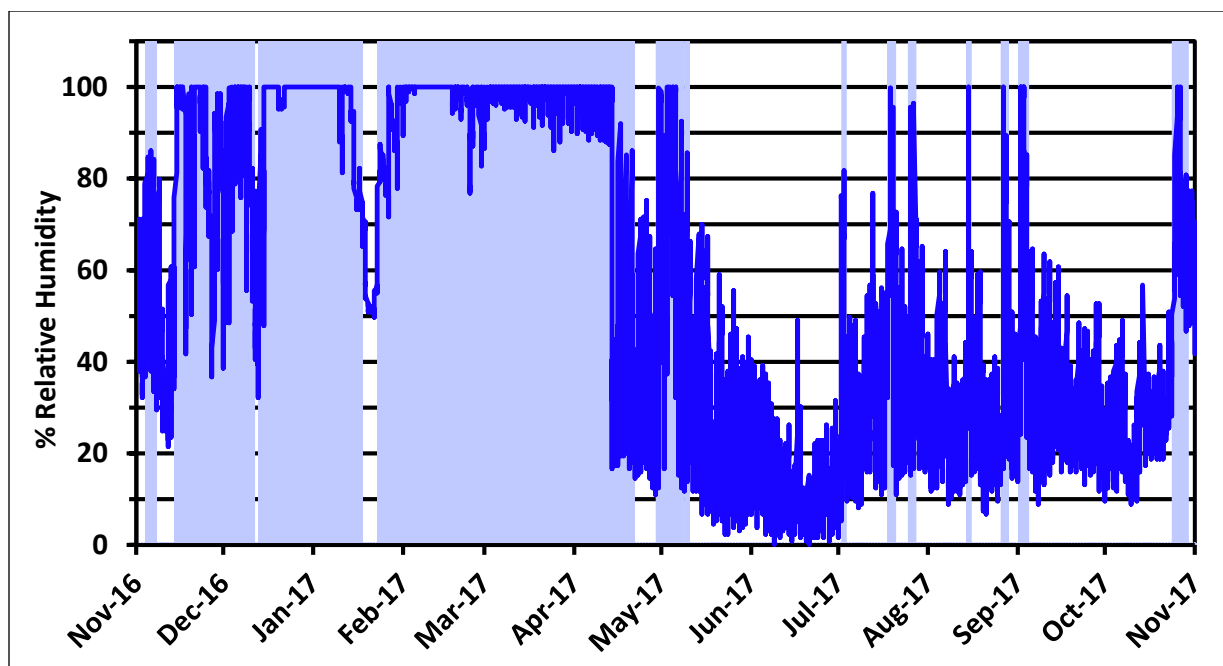


Figure 12. Continuous sensor data from Willow Spring, LAKE. The dark blue line shows the % relative humidity data downloaded from the sensor. The light blue shading shows where the % relative humidity is at or above 80 %, corresponding to the period when surface water was most likely present at the spring.

2.5.4 Water Quality (SOP 7)

The NPS Water Resources Division has identified four “core” water quality parameters to be measured at freshwater monitoring sites: temperature, pH, specific conductance, and dissolved oxygen. Water quality parameters are measured as close as possible to the spring source. Field crews will calibrate and maintain the water quality instrument according to the standards established by the manufacturer and the quality-assurance procedures developed by the USGS.

2.5.5 Site Condition: Spring Vegetation (SOP 8)

This protocol documents basic features of the vegetation community at springs. Since it would be too resource intensive to thoroughly monitor vegetation at all springs in the protocol, vegetation data are collected to provide a qualitative assessment of site condition and are not intended to address complex long-term monitoring objectives regarding trends in the vegetation community. For each spring, Field crews will:

- Visually define a buffer area of 2 m around the spring source and 20 m down the springbrook (Figure 13). Special cases for defining the buffer area are described in SOP 8: Site Condition: Spring Vegetation.
- Rank each life form category within the buffer in order of greatest to least canopy cover, with a rank of 1 signifying the greatest cover.
- Identify the dominant species within each life form category to the best of their ability, using “unknown” when necessary.

- Take one or more photographs of the dominant species within each life form category. These photographs allow the dominant species to be identified or verified by the network Ecologist at a later time if a need arises for that information.

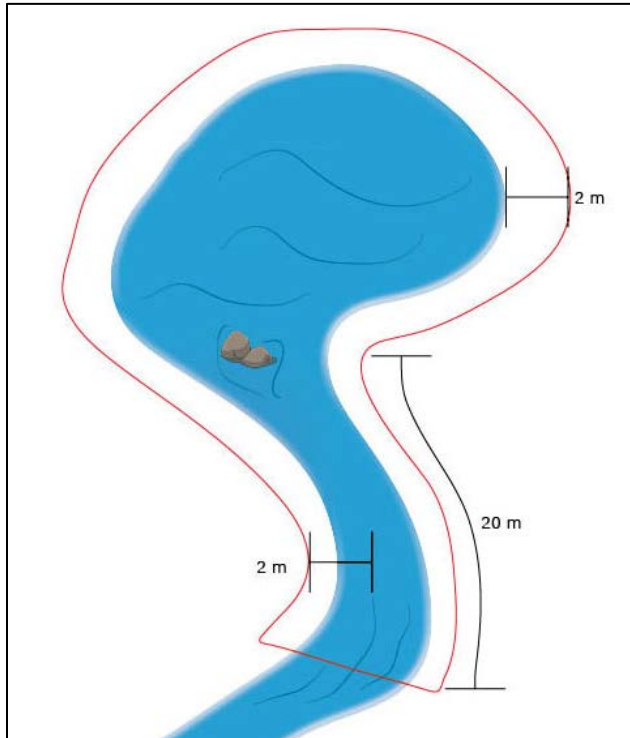


Figure 13. Schematic of buffer area around spring in which riparian vegetation is evaluated. Buffers for different spring types are described in SOP 8: Site Condition: Spring Vegetation.

2.5.6 Site Condition: Invasive Plants (SOP 9)

MOJN I&M has worked with park managers to develop priority lists of invasive plants for each park. The MOJN I&M Invasive Plant Guide for National Parks in the Mojave Desert Network (MOJN I&M 2016) is written for non-technical users and contains information on the identification of targeted invasive plants. Field crews for this protocol will use the guide to identify invasive plants encountered at springs or on the way to and from springs following Tier 3 monitoring detailed in the IPSED plan (Hupp et al. 2017). Observations will be recorded using the iNaturalist or Arc Collector smartphone applications, and location data will be uploaded into NISIMS used by the LAKE EPMT.

2.5.7 Site Condition: Disturbance (SOP 10)

Field crews record the presence of active or historical flow modification at springs, such as pipes or excavations. They also identify and assess the cover of anthropogenic and natural disturbance at springs. Anthropogenic disturbances may include roads, recreation, and livestock, while natural disturbances may include fire and flooding. Field crews also document the presence of wildlife or any evidence of wildlife use at springs, such as scat or tracks.

2.5.8 Site Condition: Repeat Photographs (SOP 11)

Repeat photographs can be powerful visual tools for recognizing and communicating landscape and ecosystem change over time. Field crews take photographs at the source of each spring as well as from upstream and downstream of the spring looking toward the source. These spring photographs will be used to monitor coarse changes in vegetation and disturbance. Sensor photographs will be used primarily to relocate sensors from year to year.

3. Field Methods and Logistics

3.1 Standard Operating Procedures

The Standard Operating Procedures (SOPs) for the MOJN I&M Desert Springs protocol are listed in Table 8 and more fully described in a companion document to this narrative. There is no quality assurance SOP for this protocol, since a standalone Quality Assurance Plan (QAP) will be published separately for this and other network protocols in accordance with I&M Program guidance. Detailed safety SOPs are provided in the MOJN I&M Field Safety Plan (Tallent et al. 2017). Data collected for this protocol are listed in Table 9.

Table 8. List of Standard Operating Procedures (SOPs).

Title	Description
SOP 1: Staff Training and JHA	Describes the training requirements for the protocol, including data collection and safety.
SOP 2: Field Mobilization and Demobilization	Describes the preparation necessary for field work as well as the proper inventory and storage of equipment and vehicles.
SOP 3: Equipment Disinfection	Describes the process for disinfecting field equipment that comes into contact with water or muddy substrate.
SOP 4: Spring Acceptance and Classification	Describes the methods for accepting springs and classifying them according to spheres of discharge.
SOP 5: Water Availability: Flow Condition	Describes the methods for assessing flow condition, measuring discharge, and recording surface water dimensions.
SOP 6: Water Availability: Data-Logging Sensors	Describes the methods for deploying and retrieving continuous data-logging sensors in the field as well as programming them in the office.
SOP 6: Water Quality	Describes the methods for measuring the four water quality parameters as well as for calibrating and maintaining the water quality instrument.
SOP 8: Site Condition: Spring Vegetation	Describes the methods for classifying and estimating the rank of vegetation lifeforms and for recording dominant plants at springs.
SOP 9: Site Condition: Invasive Plants	Describes the methods for identifying and reporting targeted invasive plants at springs.
SOP 10: Site Condition: Disturbance	Describes the methods for assessing disturbance, including flow modification, as well as for recording wildlife evidence at springs.
SOP 11: Site Condition: Repeat Photographs	Describes the methods for visually documenting springs, including photographs at the source and from upstream and downstream.
SOP 12: Data Analysis and Reporting	Describes the reporting requirements for the protocol and the details of data analysis, including statistical analyses.
SOP 13: Data Management	Describes the process for information workflow, database design, and other data management concerns.

Table 9. Data collected at desert springs. Not all parameters are applicable to all springs.

Category	Parameters
Metadata	• Spring Name • Spring ID • Park Code • Visit Date • Visit Time (24h) • Observers • GPS ID • UTM Datum and Zone
Spring Overview	• Visit Type • Monitoring Status • Rejection Criteria • Spring Type • Comments
Water Availability	• Flow Condition • Discharge Method • Discharge (L/min) • Volume of Container (mL) • % of Flow Captured • Fill Time(s) • Discharge Comments • Surface Water Width (m) • Surface Water Length (m) • Channel Description
Sensor Information	• Sensor Deployment Status • Deployment Time (24h) • Sensor Retrieval Status • Retrieval Time (24h) • Retrieval Problem(s) • Sensor Type • Sensor ID • Comments

Table 9 (continued). Data collected at desert springs. Not all parameters are applicable to all springs.

Category	Parameters
Water Quality	• Data Collection Status • Rejection Criteria • pH Instrument ID • WQ Instrument ID • Calibration Readings • Temperature Readings (°C) • pH Readings • pH Standards Used • Corrected pH Standards • Specific Conductance Readings (µS/cm) • Conductivity Standard Used (µS/cm) • Dissolved Oxygen Readings (%) • Dissolved Oxygen Readings (mg/L) • Atmospheric Pressure (mmHg) • Comments
Spring Vegetation	• Vegetation Presence • Mistletoe Presence • Life Form Ranks • Dominant Species (If Known) • Camera ID • Memory Card # • File #s • Comments
Invasive Plants	• Species (If Known) • Presence in Buffer • UTM Coordinates • Error (m) • File #s • Comments
Disturbance	• Flow Modification Status • Modification Type(s) • Anthropogenic Disturbance Class • Natural Disturbance Class • Overall Disturbance Class • Comments
Wildlife Evidence	• Animal Type • Evidence Type • Species (If Known) • Notes
Repeat Photographs	• Camera ID • Memory Card # • File #s • UTM Coordinates • Comments

3.2 Field Season Preparations

3.2.1 Permitting and Compliance

NPS Scientific Research and Collecting Permits are required for each park where the protocol will be implemented. After these permits have been approved, Investigator Annual Reports (IARs) are due every year prior to March 31. It is critical that the proper channels be followed in completing the permit process. As of 2018, permit applications and IARs can be submitted online at:

<https://irma.nps.gov/rprs/>. Permitting is the responsibility of the Protocol Lead.

As part of the permit process for each park, MOJN I&M has been given approval to install data-logging sensors at certain springs in wilderness. Each park has its own process for complying with the Wilderness Act, and MOJN I&M will continue to work through these processes with park compliance staff.

In addition to Scientific Research and Collection Permits, the NPS Pacific West Region requires that I&M networks prepare Protocol Readiness Review Certifications (RRCs) to be signed by the Superintendent of each park where the protocol will be implemented during the fiscal year. The Protocol Lead will meet with park Superintendents to discuss the field season schedule, establish safety procedures and points of contact, and answer any questions the Superintendents may have. These meetings will occur approximately two to six weeks before the beginning of the field season.

3.2.2 Staff Hiring and Training

The Protocol Lead and Program Manager will work together to assess staffing needs for the field season and hire additional employees if necessary. The exact timelines for hiring will be dictated by NPS Human Resources and may vary from year to year, but planning should occur early in the summer before the field season. Temporary or seasonal personnel may be hired through task agreements with organizations that have been awarded master cooperative agreements with the NPS. New field crew members will be brought on in early October and will begin training immediately.

The Protocol Lead will coordinate with other network personnel to train field crews in safety procedures. This includes formal and on-the-job training in park orientation, map and GPS navigation, communications devices, radio etiquette, check-in procedures, and 4-wheel drive vehicles. Network personnel will discuss the lessons learned from previous field work-related incidents as well as the hazards commonly encountered while working in backcountry desert and mountainous environments.

In addition, field crew members are required to complete a wilderness first aid course. All network personnel, including employees and volunteers, are also required to complete an Operational Leadership course, which covers situational awareness and good decision making skills. For more information on safety procedures and training, refer to the MOJN I&M Field Safety Plan (Tallent et al. 2017).

The Protocol Lead will train field crews in data collection methods while accompanying them to their first three or four springs of the field season. These methods include characterizing springs, calibrating and using the water quality instrument, measuring volumetric discharge, deploying the

data-logging sensors, identifying and ranking vegetation lifeforms, assessing disturbance, and taking repeat photographs. The Data Management Team will also train field crews in data entry best practices and basic QA/QC procedures.

The network Ecologist, or any other personnel sufficiently skilled in botany, will train field crews in the basic plant identification skills needed to assess site condition at desert springs. The Ecologist will provide training as needed to identify common native and targeted invasive plants as well as guidance on decontaminating gear to hinder the spread of invasive plants from spring to spring. The Ecologist will also train field crews on how to implement IPSED data collection at springs.

3.2.3 Field Mobilization

The field season each year will generally be conducted from early November through the middle of April (Figure 14). At least six weeks before the field season, the Protocol Lead will verify that all supplies have been purchased and equipment is in working order. Field vehicles will be checked for routine maintenance. The Protocol Lead will meet with resource management and law enforcement staff from the parks being visited to ensure that field crews are accounted for and aware of park regulations. The Protocol Lead will also make sure that the necessary Scientific Research and Colling Permits have been approved and that RRCs have been signed by the Superintendents.

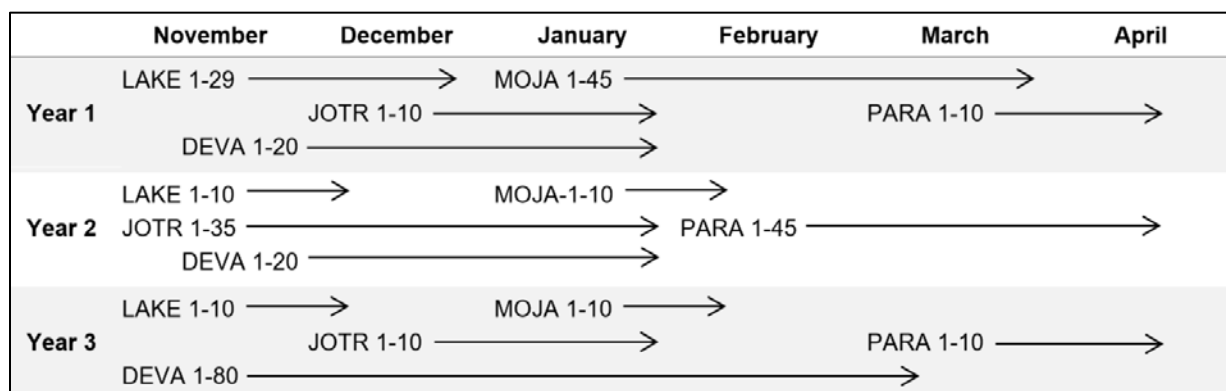


Figure 14. Three-year monitoring schedule for the MOJN I&M Desert Springs protocol. The numbers after the park codes indicate which springs will be monitored each year (e.g., 1-10 indicates the first 10 springs in the GRTS draw).

At least one week before field work, the Field Crew Lead will assemble a site packet (containing daily itineraries, driving and hiking routes, topographic maps, locations of nearest medical services, weather forecasts, and emergency contact numbers) and backcountry travel plan. NPS employees will submit travel authorizations through Concur (<https://cge.concursolutions.com/default2.asp>), and interns and volunteers will make sure that they are able to receive travel reimbursements through their sponsor organization. The Field Crew Lead or Protocol Lead will arrange for a fee-waived camping permit or park housing, if necessary. The Protocol Lead will email relevant park staff with a reminder of the dates and locations where field crews will be working and camping, if applicable.

The day before field work, field crew members will assemble the necessary equipment and supplies and double-check that all equipment is charged and in working order. They will load the equipment into the field vehicle for prompt departure the following day. The Field Crew Lead will submit the backcountry travel plan via email or fax to the dispatch responsible for the park in which the field crew will be working. Individual park staff may also want to receive a copy of the backcountry travel plan. Detailed mobilization procedures and checklists are provided in SOP 2: Field Mobilization and Demobilization.

3.3 During the Field Season

3.3.1 Three-Year Monitoring Calendar

The rotating panel design described in Chapter 2 of this protocol consists of annual visits for 60 springs and three-year visits for the remaining springs. The three-year monitoring schedule for the protocol is shown in Figure 14. The calendar was developed with the following goals:

- monitoring each spring during the same 30-60 day window each year,
- monitoring springs in LAKE first to maximize field crew interactions with the Protocol Lead, Program Manager, and Data Management Team early in the field season, and
- monitoring high-elevation springs in DEVA and PARA, where snow and ice conditions restrict winter access, either in early November or in March and April.

The 2015-16 pilot season was considered a partial implementation of Year 1, so the 2016-17 field season was Year 2, the 2017-18 field season was Year 3, and the 2018-19 field season will be Year 1 again, etc.

3.3.2 Site Access

Some springs are located close to drivable roads, but field crews will generally reach sites by hiking long distances over potentially difficult terrain. Site packets containing daily itineraries, driving and hiking routes, topographic maps, locations of nearest medical services, weather forecasts, and emergency contact numbers have been prepared for each spring. Driving and hiking routes for each spring and the locations of medical services for each park can be found in the *Implementation* folder within the *DS_Water* folder on the MOJN I&M server. Blank backcountry travel plans, which include fields and drop-down menus for daily itineraries, weather forecasts, and emergency contact numbers, can be found in the *1_BACKCOUNTRY_TRAVEL_PLANS* folder within the *Safety* folder on the MOJN I&M server. Topographic maps can be found in the map filing cabinet in the MOJN I&M office.

3.3.3 Data Collection

Data collection for the MOJN I&M Desert Springs protocol is intended to take an hour or less to complete at each spring. The first thing field crews should do upon reaching a spring is to begin calibrating the water quality instrument. This procedure can take nearly 30 minutes depending on the instrument being used, and starting calibration early in the visit allows the crew to collect other data while waiting for the instrument to equilibrate. Volumetric discharge measurements should be made after water quality is measured, since they can disturb the springbrook sediment and alter water

quality. Instructions for specific field methods can be found in SOPs 4-11. The field data sheet for the protocol can be found in Appendix A of the SOPs for this protocol (Bailard et al. 2018).

3.3.4 Equipment Decontamination

Field crews have the potential to introduce and spread pathogens and invasive organisms, so they will check their equipment, camping gear, and personal belongings for biological material (i.e., seeds, insects) before leaving the field. Camping gear, backpacks, clothing, and other belongings that **have not** been exposed to an aquatic environment (water or muddy substrate) will be rinsed or brushed off. Boots and any equipment that **have** been exposed to an aquatic environment will be decontaminated using the procedures described in SOP 3: Equipment Disinfection.

Upon returning to the office, field crews will hose down the exterior of the field vehicle, paying particular attention to the tire treads, wheel wells, and undercarriage where mud and biological material is most likely to have accumulated.

3.4 After the Field Season

3.4.1 Field Demobilization

The field season for the MOJN I&M Desert Springs protocol is scheduled to conclude around the middle of April, depending on weather conditions (Figure 14). Field demobilization should begin immediately afterwards. Demobilization consists of cleaning, inspecting, and performing routine maintenance on field vehicles; inventorying equipment and supplies; properly storing equipment and supplies; and alerting the Protocol Lead to anything that will need to be repaired or replaced. Specific demobilization procedures are described in SOP 2: Field Mobilization and Demobilization.

3.4.2 Data Entry and QA/QC

Once field demobilization is complete, field crew members will assist the Data Management Team with data entry and initial QA/QC procedures. These procedures are described briefly in Chapter 4 of this protocol and more thoroughly in SOP 13: Data Management.

4. Data Management

Effective data management is critical to ensuring the quality, interpretability, security, longevity and discoverability of the data produced by our monitoring efforts. The principles of sound data management as they apply to this network are defined in the Data Management Guidelines for Inventory and Monitoring Networks (NPS 2008). This narrative will describe in general terms how these principles will be applied to the MOJN I&M Desert Springs protocol. A detailed set of procedures for all data management tasks can be found in SOP 11: Data Management.

4.1 Data Collection and Database Design

This protocol collects both discrete and continuous data. Discrete data collected in the field will be recorded on paper field data forms until an electronic data collecting system is deemed practical. Before leaving a spring, the Field Crew Lead is responsible for ensuring that all forms have been filled out completely and that the information on each form is logical and legible. Upon returning from each field trip, field data sheets will be scanned to PDF files. If changes are made to paper datasheets, they should be re-scanned. The Protocol Lead is responsible for the safekeeping and organization of the field data sheets until data entry and verification procedures have been completed, at which point the field data sheets are stored in fireproof cabinets in the MOJN office and eventually archived by the network Data Manager.

Discrete data will be stored in a SQL Server relational database that is based on the development work of a multi-network collaborative team. The database design is inspired by the Inventory and Monitoring (I&M) Program's Natural Resources Database Template (NRDT), but with modifications that bring it in line with the 2015 Inventory and Monitoring Division database standards (Frakes et al. 2015). Continuous data will be stored locally in its native format as well as in Excel files. The data will also be uploaded to a SQL Server relational database. The database will store metadata for photographs taken as part of each spring visit. The photographs will be renamed and stored as described in SOP 11: Data Management.

Any time a revision of the protocol requires a revision to the database, a complete copy of the database will be made and stored in an archive directory.

4.2 Data Entry, Verification, and Validation

4.2.1 Data Entry

The discrete monitoring data recorded on the paper forms will be entered into the MOJN I&M Desert Springs database. Ideally, this can be undertaken throughout the field season. Otherwise, it should occur immediately following the field season. Data entry should be completed by someone who participated in data collection, or is familiar with the project and data. The primary goal of data entry is to transfer the data from paper into the database with 100% accuracy. The database will be backed up regularly to maximize the ability to recover should irreversible errors or problems occur during the data entry session.

4.2.2 Data Verification

The springs database application will incorporate quality assurance/quality control (QA/QC) strategies to ensure data quality. The database design and the allowable value ranges assigned to individual fields within the data tables help to minimize the potential for data entry errors and the transcription of erroneously recorded data.

SOP 11: Data Management describes the steps that the Protocol Lead and Data Management Team will take to ensure that the data records within a given season's dataset are verified (i.e., database values are compared against hard-copy datasheets). The goal is to check 100% of records and to correct and track any errors discovered. The completion of data verification and other QA processes will be documented in the database. The Data Management Team will also verify the geospatial component of the desert springs database each field season.

When data verification is complete, the dataset has reached the "provisional" data processing level. The data processing levels referred to in this document are more fully described in Certification Guidelines for Inventory and Monitoring Data Products (NPS 2016).

4.2.3 Data Validation

The Protocol Lead and Data Management Team will collaboratively validate the dataset (i.e., ensure that the data make sense) for a given field season. Some validation methods have been incorporated into the database. Other, more specific, validation routines will be developed with the Protocol Lead and incorporated into the database as appropriate. The Data Management Team will work closely with the Protocol Lead to provide any needed database queries, reports, graphs, or export file formats to assist with the overall validation. When data validation is complete, the dataset has reached the "pre-certified" data processing level.

4.3 Data Certification and Documentation

Once the data have been validated, the Data Manager and Protocol Lead will complete the necessary accompanying metadata. Metadata is defined as structured information about the content, quality, condition, and other characteristics of a given dataset. Additionally, metadata provide the means to catalog and search among datasets, thus making them available to a broad range of potential users. Any records that did not meet the documented quality standards in the validation process must be clearly identified in the metadata.

When data have undergone all QC procedures and metadata are complete, then the dataset has reached the "accepted" data processing level. This is the highest data processing level that can be achieved until the full QAP has been approved for this protocol.

4.4 Data Distribution

Prior to the publication of any data or reports, MOJN I&M staff will work with a representative from each park included in the dataset to complete a data sensitivity assessment form. The results of this assessment will dictate the appropriate audience for the data: Park only, NPS only, or Public. Redacted datasets and reports may be created when it is deemed that sensitive information should be obscured for one or more of these audiences.

As part of the reporting cycle, summary reports and derived data products will be made available on the IRMA Data Store (<https://irma.nps.gov/DataStore/>). Additionally, pertinent data will be uploaded to NISIMS (<https://irma.nps.gov/NISIMS/>) and NPSpecies (<https://irma.nps.gov/NPSpecies/>).

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

4.5 Data Maintenance and Archiving

Secure data archiving is essential for protecting data files from loss or corruption. Once the master project dataset and metadata are considered final for a field season, the Data Manager will place a copy of the dataset and the metadata record into the appropriate folder within the archive directory on the MOJN I&M file server (M: drive), which is backed up to a remote location. These archived files will be stored in read-only format. Any subsequent changes made to this database must be documented in an edit log and in the metadata. In addition to the database copy in its native format, all tables will be archived in a comma-delimited ASCII format that is platform-independent.

Additional digital files to be archived include all digital photographs associated with that field season as well as any digital files associated with data analysis and reporting products. Hard-copy materials (e.g., field data sheets, field notebooks) are currently stored in the network office but will eventually be moved to an NPS-approved repository for permanent storage. Any editing of archived data must be documented in the edit log and accompanied by an explanation that includes pre-and post-edit data descriptions. Field data sheets can be reconciled to the database using the edit log.

Prior to any major changes of a dataset, a copy is stored with the appropriate version number to allow for tracking changes over time (see SOP 11: Data Management). Each additional version will be assigned a sequentially higher number. Frequent users of the data are notified of the updates and provided with a copy of the most recent version.

5. Data Analysis and Reporting

5.1 Reporting Overview

There will be three types of reporting for the MOJN I&M Desert Springs protocol:

- Each year, the certified data will be made available to the parks by uploading it to the IRMA Data Store.
- Every three years, once all springs in the sample have been visited, and annual springs in the sample have been visited three times, MOJN I&M will prepare a Data Summary Report for each park. These reports will not analyze trends in the data, but will summarize and explain the previous three field seasons of data collection. The reporting will follow the same three-year calendar as the monitoring, beginning with reports for the 2015-16 pilot season at LAKE and MOJA. The Data Summary Reports will be published in the NPS Natural Resource Data Series (NRDS).
- After twelve years, once all springs in the sample have been visited four times, and annual springs have been visited twelve times, MOJN I&M will prepare a Trend Analysis Report for each park. These reports will synthesize the information presented in the Data Summary Reports and provide statistically-rigorous assessments of trends in the data. After the first report for each park, they will be subsequently prepared every nine years. The Trend Analysis Reports will be published in the NPS Natural Resource Report Series (NRR).

5.2 Status Estimation Analysis

The Data Summary Reports will include summary statistics and graphics to convey information to park managers on the status of the springs in each park. Types of monitoring data collected to address the measurable objectives include binary data, numerical data, and sensor data. Table 10 summarizes the statistical analyses that will be performed on these data. Statistical analyses are discussed in detail in SOP 10: Data Analysis and Reporting, and they are briefly described below.

Table 10. Summary statistics and graphics for Data Summary Reports.

Measurable Objective	Parameter	Statistical Analyses	Graphics
Water Availability	Flow Condition Discharge Surface Water Length	Proportion of springs in sample with given condition -- confidence interval determined using hypergeometric distribution; sample mean for discharge; sample mean for surface water length	Maps of key variables (e.g., presence or absence of surface water)
	Sensor Data	Proportion of perennial, seasonal, and ephemeral springs; sample median dates of beginning and end of dry period	Graphical representation of wet and dry periods at each annual spring
Water Quality	Temperature pH Specific Conductance Dissolved Oxygen	Sample mean for each "core" parameter -- confidence interval calculated using finite sample size correction	Maps of "core" parameters, box and whisker plots

Table 10 (continued). Summary statistics and graphics for Data Summary Reports.

Measurable Objective	Parameter	Statistical Analyses	Graphics
Site Condition: Incidental Data	Spring Vegetation Invasive Plants Disturbance Wildlife Use	Proportion of springs in sample with given condition -- confidence interval determined using hypergeometric distribution	Maps of specific variables of management interest (e.g., presence or absence of livestock)

5.2.1 Binary Data

Many of the observations made for this protocol can be thought of as binary data, that is, data with only two possible outcomes. Examples of this include the presence or absence of surface water, the presence or absence of particular invasive plants, the presence or absence of different vegetation lifeforms, or the presence or absence of different types of disturbance. In these cases, the best park-wide summary statistic is the proportion of springs in which a certain condition is observed (e.g., percentage of springs with surface water). As described in SOP 10: Data Analysis and Reporting, the sample is drawn from a fixed population without replacement, so the confidence interval for this proportion can be determined using the Clopper-Pearson approach for the hypergeometric distribution (Clopper and Pearson 1934).

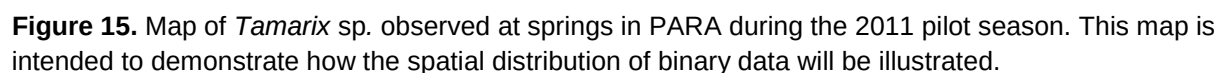
The spatial distribution of these parameters can be presented using maps (e.g., Figure 15). The Protocol Lead will determine which parameters should be mapped in each report to best communicate the results of monitoring to the parks. Other maps could include springs that have switched from one binary category to the other since the prior report.

An important consideration with binary data is ensuring that, when a data point is not collected at a spring, this lack of data is not recorded, analyzed, or displayed as an absence. Where possible, the field data sheets have been designed to prompt field crews to circle either “yes” or “no” or else to circle one or more options from a list when recording data. This built-in quality assurance step allows for the distinction between confirmed absence (e.g., “no” or “none” circled) and missing data (e.g., nothing circled).

5.2.2 Numerical Data

The measurements of water quality parameters, discharge, and surface water length are numerical data. The relevant summary statistic for the water quality parameters and discharge is the sample mean, with the confidence limits determined using a finite population correction factor (e.g., Jarrell 1994). Surface water lengths are recorded as “>50 m” for all lengths greater than 50 m, so the sample median will be used instead of the sample mean. For all numerical parameters, maps will be used to illustrate geographic distribution of parameter values (e.g., Figure 16), and box plots will be used to display the distribution of the sample data (e.g., Figure 17). The Protocol Lead will determine which parameters should be mapped and plotted in each report to best communicate the results of monitoring to the parks.

Vegetation lifeform data are intended to describe site condition and detect coarse changes in the vegetation community at a spring. These data are recorded as ranked data, where the lifeform with the greatest amount of cover is ranked first, and so on. As mentioned above, the presence or absence of a particular lifeform can be treated as binary data. In addition, reports will include a table showing the proportion of springs in the sample that had each lifeform ranked highest as well as a table showing the proportion of springs in the sample where each lifeform was observed. The Protocol Lead will determine which parameters should be mapped in each report to best communicate the results of monitoring to the parks.



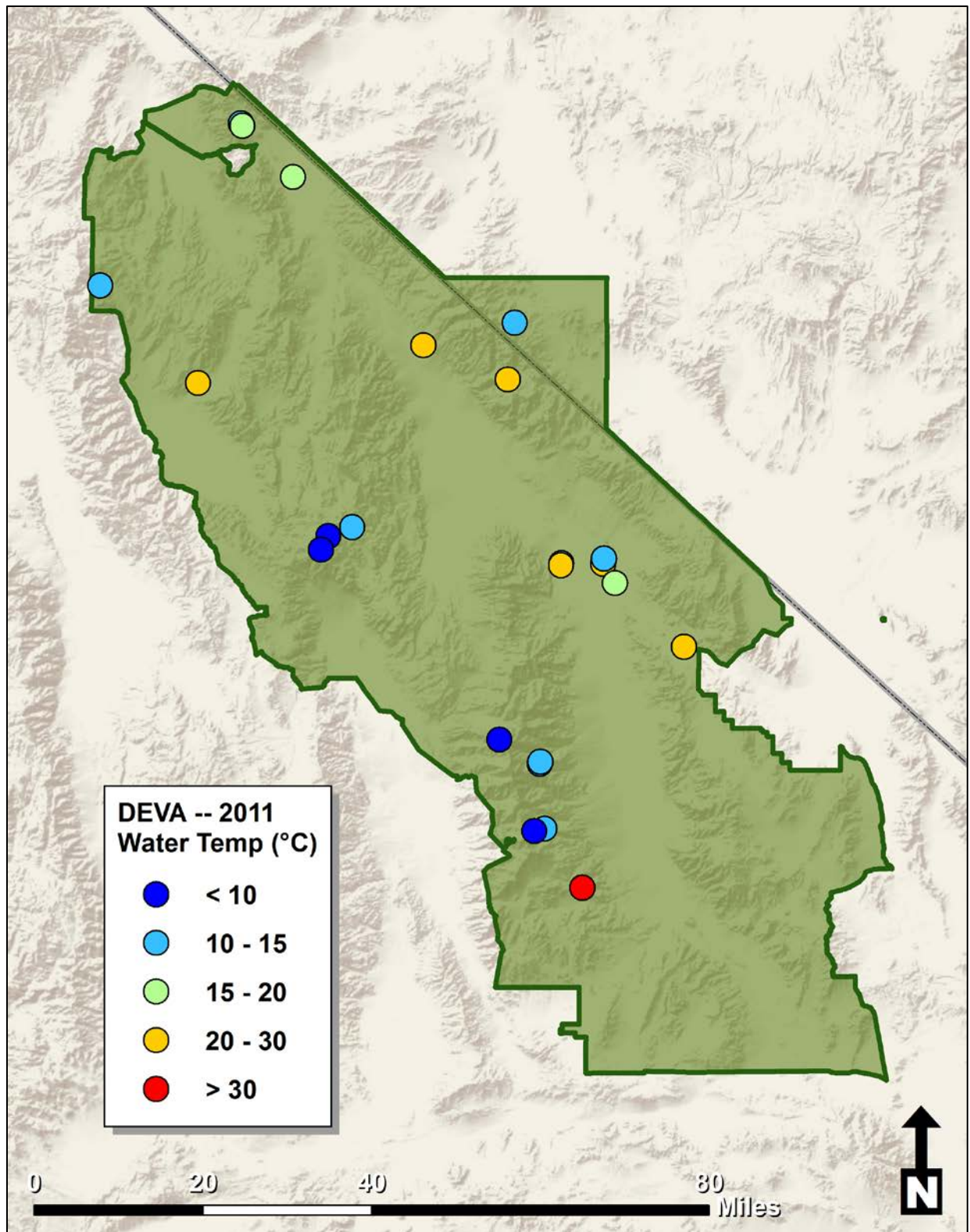


Figure 16. Map of water temperatures (°C) measured at springs in DEVA during the 2011 pilot season. This map is intended to demonstrate how the spatial distribution of numerical data will be illustrated.

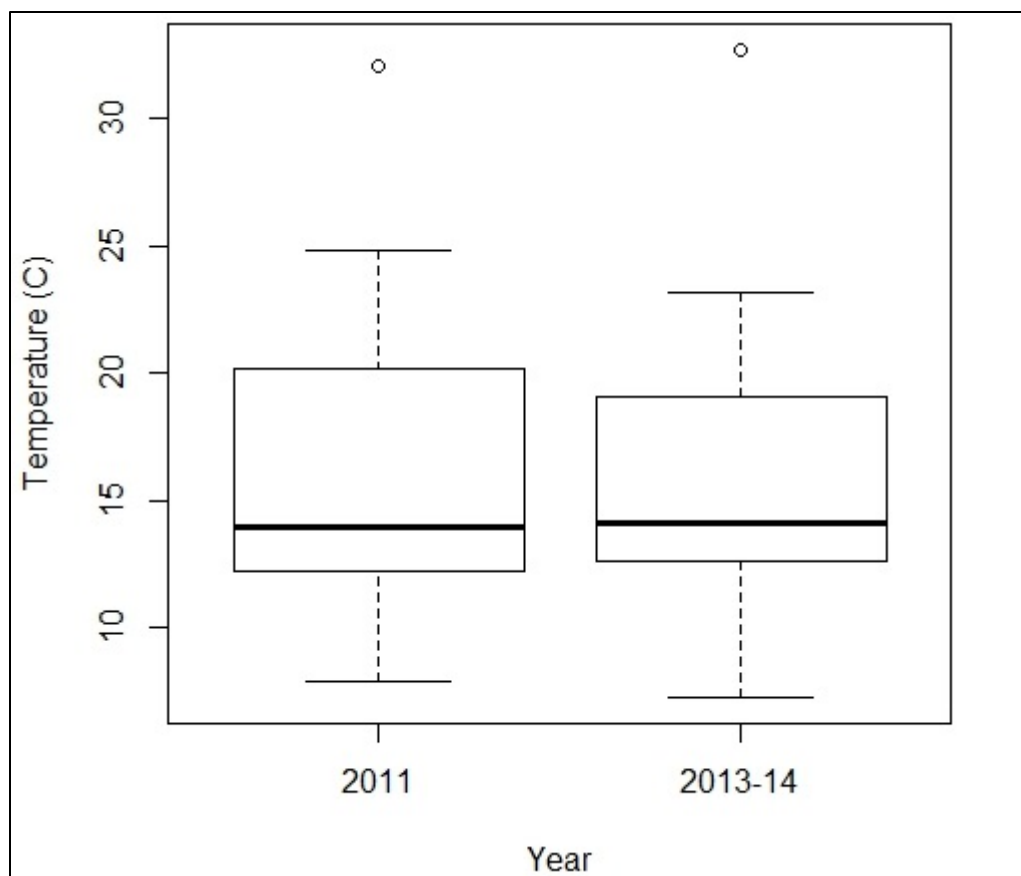


Figure 17. Box plots for water temperatures (°C) measured at springs in DEVA springs during two pilot field seasons. The thick line is the median.

5.2.4 Sensor Data

The sensor records will be converted into records of wet and dry periods using a threshold of 80% relative humidity. Summary information derived from these records will include:

- Proportions of perennial springs, seasonally wet springs, and ephemeral springs without an extended wet period.
- Median dates of beginning and end of dry period for seasonally wet springs.
- Graphical representation of when each spring was wet (e.g., Figure 18).

These data will be discussed in the context of precipitation patterns in each park over the period of record. Note that the metrics described above are relatively insensitive to brief periods of false positives (e.g., when atmospheric humidity briefly exceeds 80%) or false negatives (e.g., when a sensor is briefly knocked out of the water by debris or wildlife).

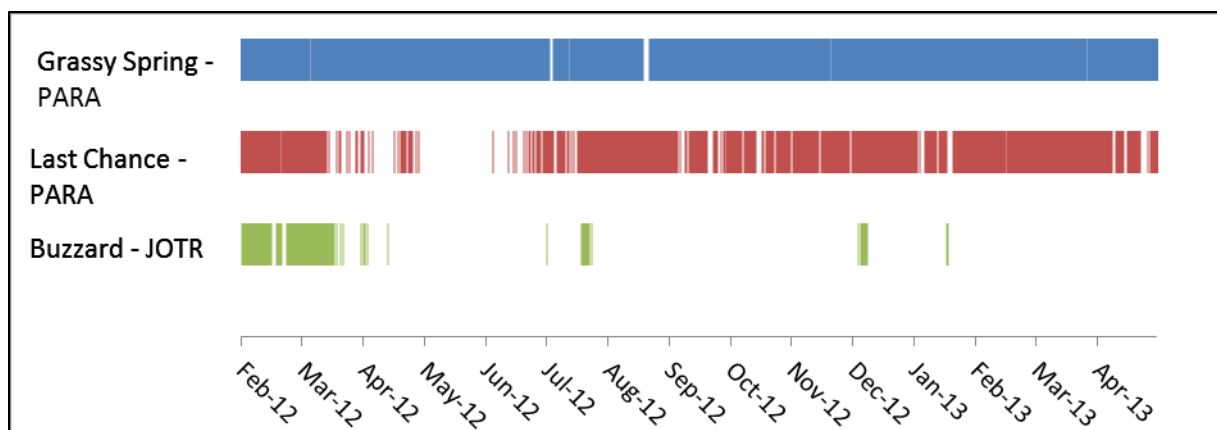


Figure 18. Wet (solid color) and dry (no color) periods for three springs derived from sensor data. Grassy Spring is perennially wet. Last Chance Spring is seasonally dry. Buzzard Spring does not have an extended wet period in Water Year 2013.

5.3. Trend Analyses

When adequate temporal replication of monitoring data is available, trends will be estimated and tested for statistical significance to assess how water availability and water quality are changing over time. In the model selection process, the Protocol Lead must determine if parametric or non-parametric methods are appropriate. In other words, parametric and nonparametric approaches will be considered based on the nature of the data, underlying model assumptions, and desired inference.

Qualitative data and site condition information can be used as explanatory variables in analysis if appropriate (e.g., if the data describe variation and are not strongly correlated with the response variable). However, they are not described in detail here as they do not directly address the measurable objectives.

Trend Analysis Reports will include summary statistics and graphics to convey information to park managers on the trends of the springs in each park. Types of monitoring data include binary data, numerical data, censored data, and bounded data. Table 11 summarizes the statistical analyses that will be performed on the data. Statistical analyses are discussed in detail in SOP 10: Data Analysis and Reporting, and they are briefly described below.

Table 11. Summary statistics and graphics for Trend Analysis Reports. This table describes the parameters in terms of their data type.

Measurable Objective	Parameter	Data Type	Statistical Analyses
Trends in Water Availability	Flow Condition	Categorical	GLMM
	Surface Water Length (m)	Numerical (censored)	GLMM, but correct data using substitution, maximum likelihood methods, regression on order statistics, etc.
	Discharge (L/min)	Numerical (censored)	GLMM, but correct data using substitution, maximum likelihood methods, regression on order statistics, etc.
	Sensor data (presence / absence of surface water)	Binary (bounded)	GLMM, but bounded data must be transformed
Trends in Water Quality	Temperature (°C)	Numerical (continuous)	GLMM, or Regional Kendall Tau test
	pH	Numerical (continuous)	GLMM, or Regional Kendall Tau test
	Specific Conductance (μS/cm)	Numerical (continuous)	GLMM, or Regional Kendall Tau test
	Dissolved Oxygen (mg/L, %)	Numerical (continuous)	GLMM, or Regional Kendall Tau test

5.3.1 Binary Data

Trends in the probabilities of binary data (e.g., the proportion of springs that were dry at the time of visit) will be analyzed using binomial generalized linear mixed models (GLMM). These models provide a flexible framework to consider trends in a binary outcome while also considering random variation among years and springs (McCulloch et al. 2008).

5.3.2 Numerical Data

Continuous numerical data that take values on the real-number line may be modeled with linear mixed models, given that parametric assumptions are met. The linear mixed model of Piepho and Ogutu (2002) is a flexible model for estimating trend as well as the contribution of the variance by components such as spring-to-spring variation, year-to-year variation, and variation among spring-level trend lines. Some numerical data, such as water quality parameters, will only be measured at springs where water is present at the time of the visit. Note that measurements cannot be taken for dry springs, so trends in water quality parameters may be best interpreted in tandem with trends in the proportion of dry springs.

When parametric assumptions are not met, a nonparametric trend analysis such as the Regional Kendall Tau test (Helsel and Frans 2006) may be used to conduct a hypothesis test for a non-zero trend. This nonparametric test requires that each spring be visited at least four times in order to be used in the trend analysis. The Regional Kendall trend test does not require assumptions of normality, is robust to outliers, and is invariant to power transformations (i.e., logarithmically-

transformed data will yield the same trend test results as untransformed data). However, the p-values for the Regional Kendall Tau trend test are not interpretable when data are serially correlated (Helsel and Frans 2006). Once sufficient data are available (sample size of approximately 20), trend-free pre-whitening is recommended to remove serial correlation (Yue et al. 2002) from the time series prior to testing. Trend-free pre-whitening removes the effects of serial correlation without diminishing trend magnitude or the power to detect trend.

5.3.3 Censored Data

This protocol also collects data that are censored. An example is spring discharge, for which any measurement less than 1 liter per minute is left-censored. Trend analysis specific to censored data must be used and may include simple substitution, maximum likelihood methods, regression on order statistics, and the robust parametric method of filling in missing values (Helsel 2005, Manly 2001). Analysis tools in R packages such as NADA (Lee 2013) and censReg (Henningsen 2013) can be used to obtain unbiased estimates of trend in censored data.

5.3.4 Bounded Data

Some data collected for the protocol are bounded, and trend analysis must accommodate these data. For example, the Julian date on which a spring went dry or started flowing will be tracked across years to detect trends in the drying and onset of seasonal flow. These data are bounded in the interval of 0 to 365 days (or 366 for leap years). If the data do not meet the standard assumptions for linear models, such as normality and homoscedasticity (homogeneity of variance), then one approach may be to transform the data into proportions of the year and model these proportions with a logit transformation. Alternatively, a nonparametric trend analysis such as the Regional Kendall Tau test (Helsel and Frans 2006) may be used to detect non-zero trend.

5.4. Protocol Revision and Review

5.4.1 Revision

We anticipate that it will be necessary to revise protocol documents (narrative and SOPs) in the future as methods and technology evolve. Changes should be made only after careful consideration of the comparability of past and future data and the statistical validity of the protocol as a whole. Small changes or additions to existing methods will be reviewed in-house by MOJN I&M staff. Substantive changes will require external peer review. All changes to a protocol document will be recorded in its revision history log, including the rationale for the change and the field season in which the change was implemented. If any protocol documents are changed, an updated “protocol package” of all SOPs will be uploaded to the IRMA Data Store as described in SOP 11: Data Management.

5.4.2 Review

The success of protocol implementation will be reviewed by MOJN I&M staff following the first year of field work. Thereafter, the protocol will be formally reviewed and evaluated once the preparation of the Trend Analysis Reports has given network staff a sense of the effectiveness of the monitoring program. This formal review will include assessment of data collection and analysis methods. If any changes to the methods described in the protocol narrative or SOPs are required, then revisions to the protocol documents would happen at this time.

6. Personnel Requirements

6.1 Staffing

6.1.1 Protocol Lead

As the primary staff member in charge of water resource monitoring for the network, the MOJN I&M Physical Scientist (or similar position) will be Protocol Lead for the MOJN I&M Desert Springs protocol. It is expected that the Protocol Lead will devote approximately 1/3 of his or her time to the MOJN I&M Desert Springs protocol.

6.1.2 Field Crew

The field crew will consist of a Field Crew Lead and at least two dedicated field crew members. The Field Crew Lead can be the Protocol Lead or a Science Technician (e.g., Hydrologic, Physical Science, Biological Science). Additional field crew members may be Science Technicians, interns, or volunteers. Field crews are not exclusively limited to these personnel. Other MOJN I&M staff members may also participate in protocol implementation during the field season as long as they have been trained in safety and data collection according to the SOP 1: Staff Training and JHA.

Field crews typically work in pairs when implementing the protocol. If there are multiple field crews working simultaneously, each field crew must include at least one NPS employee. The Field Crew Lead and field crew members will work on the MOJN I&M Desert Springs protocol for a minimum of 24 weeks. Their duty station will be the MOJN I&M office at LAKE.

6.1.3 Other Staff

Other MOJN I&M staff members that are involved with the protocol include the Program Manager, Data Manager and Assistant Data Manager, and Ecologist. These are all NPS employees based at the MOJN I&M office at LAKE. Their time commitments to the protocol vary by role. In the future, the network may hire or provide partial funding for a Quantitative Ecologist who would assist with statistical trend analysis and spend part of their time on the MOJN I&M Desert Springs protocol.

6.2 Roles and Responsibilities

The roles and responsibilities of protocol personnel are given in Table 12.

Table 12. Roles and responsibilities for implementing the MOJN I&M Desert Springs protocol.

Role	Responsibilities
Protocol Lead Physical Scientist GS-09 (or similar)	Manages protocol oversight, administration, and implementation. Facilitates communications with park managers. Collaborates with Program Manager on tracking budget, personnel requirements, and progress toward meeting monitoring objectives. Coordinates and ratifies changes to protocol. Trains field crews in data collection and safety SOPs. Participates in field crew efforts at springs, if necessary. Certifies each field season's data for quality and completeness. Conducts data analysis and prepares annual data summary reports according to schedule.
Field Crew Lead Science Technician GS-07	Coordinates and leads field work for the field season. Prepares site packets and backcountry travel plans. Makes measurements and records observations at desert springs according to data collection SOPs. Enforces safety SOPs in the field. Initiates data entry, data QA/QC, data analysis and reporting, and field equipment management, as needed. Oversees day-to-day operations.
Field Crew Members Science Technician GS-05 and / or Intern and / or Volunteer	Participates in field work at all parks. Assists Field Crew Lead with measurements and observations at springs by following data collection SOPs. Adheres to safety SOPs in the field. Assists Field Crew Lead with data entry, data QA/QC, field logistics, and field equipment management, as needed.
Program Manager GS-13	Provides supervision and oversight of the Protocol Lead. Manages administration, budget, and personnel. Consults on all phases of protocol revision and implementation. Reviews data summary and trend reports.
Data Management Team Data Manager GS-11 Asst. Data Manager GS-07/09	Facilitates review and posting of data, metadata, reports, and other documents to national databases according to schedule. Serves as primary steward of Access database and GIS products. Maintains and updates database application. Trains field crews in data entry and QA/QC SOPs. Archives project records and field data sheets. Performs automated data summaries and analyses. Conducts the initial GRTS draw for spring sampling.
Ecologist GS-09/11	Trains field crews in riparian and invasive plant identification, vegetation life form classification, and related methodology. Assists with identification of unknown plants in the office.
Quantitative Ecologist GS-12	Conducts statistical analysis on data and prepares trend reports according to schedule.

6.3 Qualifications

The Protocol Lead will meet the basic requirements for a Physical Scientist GS-09 (or similar), including education and/or experience in field sampling, data analysis, and water quality assessment. Experience with backcountry operations and wilderness safety is desired. Recent Inventory and Monitoring Division (IMD) guidance also requires at least one staff member per network to complete and maintain certification in an approved water quality field methods training course. The Protocol Lead will be responsible for meeting this requirement and for training field crews on water quality methods based on best practices learned in the course.

The Field Crew Lead is required to have education and/or experience in natural resource monitoring and collecting water quality data in the field. Previous experience leading field crews and working in the Mojave Desert is desired. Field crew members should be selected based on their ability to operate safely in the backcountry with minimal supervision. The Ecologist must have sufficient skills to train field crews on how to identify riparian and invasive plants as well as how to implement IPSED data collection at springs. Details on training for data collection methods, safety, and other requirements are found in SOP 1: Staff Training and the MOJN I&M Field Safety Plan (Tallent et al. 2017).

7. Operational Requirements

7.1 Facilities, Vehicles, and Equipment

No specialized facilities are needed to support field work for the MOJN I&M Desert Springs protocol. The network currently has three 4-wheel drive vehicles. At least one of these vehicles will be needed for most weeks during the field season.

The water quality component of the protocol will require the use of an appropriate water quality instrument and associated buffer solutions and standards. A waterproof digital camera will be provided for repeat and incidental photographs. In addition, safety equipment and communications devices (e.g., handheld radios, satellite phones, and personal first aid kits; see MOJN I&M Field Safety Plan) will be supplied by MOJN I&M to field crews.

7.2 Yearly Schedule

The annual workload of this monitoring protocol is outlined by the tasks listed in Table 13. Field season preparations begin in July with planning activities. Data certification and reporting and other close-out activities conclude by June of the following year. Field work is conducted primarily from early November through April to avoid extreme heat conditions during the summer, although field work during sub-freezing conditions in winter will also be avoided. Data entry and QA/QC may occur throughout the field season when field crews have downtime in the office.

Table 13. Annual implementation schedule for the MOJN I&M Desert Springs protocol.

Month	Administration	Field Work	Data Management
July	Plan crew staffing	–	–
August	Check status of permits	Order supplies	–
September	Ensure RRCs are signed	Plan field schedule	–
October	Crew starts	Crew training and mobilization	–
November	–	Field work	Data entry and QA/QC
December	–	Field work	Data entry and QA/QC
January	–	Field work	Data entry and QA/QC
February	–	Field work	Data entry and QA/QC
March	Complete IARs	Field work	Data entry and QA/QC
April	–	Field work and demobilization	Data entry and QA/QC
May	–	–	Certification
June	–	–	Reporting

The MOJN I&M Desert Springs schedule is coordinated with the summer schedule for the MOJN I&M Streams and Lakes protocol and the quarterly schedule for the MOJN I&M Selected Large Springs protocol, with little activity scheduled from June through September in order to accommodate the Streams and Lakes field season in GRBA.

7.3 Budget

The estimated annual operating budget for the MOJN I&M Desert Springs protocol is \$104,676. Details are provided in Table 14. Labor costs include the estimated current fully burdened (includes benefits) hourly rate for each position.

Table 14. Estimated annual budget for MOJN I&M Desert Springs protocol.

Expense Type	Expense	Annual Cost
Equipment	Data-logging sensors and associated expenses	\$3,000
	Water quality instrument maintenance and standards	\$200
	Total for Equipment	\$3,200
Labor	Program Manager GS-13 (1 week)	\$2,340
	Protocol Lead GS-09 (14 weeks)	\$17,920
	Ecologist GS-09/11 (1 week)	\$1,454
	Quantitative Ecologist GS-12 (1 week)	\$2,019
	Science Technician (Field Crew Lead) GS-07 (20 weeks)	\$21,800
	2 nd Science Technician GS-05 or Field Crew Intern (24 weeks)	\$22,080
	Data Manager GS-11 (8 weeks)	\$14,573
	Assistant Data Manager GS-07/09 (8 weeks)	\$10,240
	Science Technician (Data Management) GS-07 (5 weeks)	\$5,450
	Total for Labor	\$97,876
Travel	–	\$3,600
Total Cost	–	\$104,676

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Appendix A. Ordered Lists of Springs from GRTS Draws

Table A-1. Ordered Lists of Springs from GRTS Draws.

Park	GRTS	Name	Sample Type
DEVA	1	Valley Spring	Annual
DEVA	2	Greenwater Spring	Annual
DEVA	3	Panamint Burro Spring	Annual
DEVA	4	Shrike Spring	Annual
DEVA	5	Bottle Spring	Annual
DEVA	6	Blackwater Spring A	Annual
DEVA	7	Mahogany Spring A	Annual
DEVA	8	Waucoba Spring	Annual
DEVA	9	Sister C	Annual
DEVA	10	Keane Seep (Canyon SE of Keane Wonder Mine)	Annual
DEVA	11	Winter Spring	Annual
DEVA	12	Currie Wells	Annual
DEVA	13	Poplar Spring A	Annual
DEVA	14	Little Spring	Annual
DEVA	15	Grapevine Palm	Annual
DEVA	16	Corkscrew Spring	Annual
DEVA	17	Burro Slide Spring	Annual
DEVA	18	West Twin Spring	Annual
DEVA	19	Benny Spring	Annual
DEVA	20	Lost Creek C	Annual
DEVA	21	Arrow Spring	3 Year
DEVA	22	Salty Navel Spring	3 Year
DEVA	23	Hummingbird Spring	3 Year
DEVA	24	Nelson B Spring	3 Year
DEVA	25	Jack 26	3 Year
DEVA	26	Gnome Spring M	3 Year
DEVA	27	LCM 003 Unnamed	3 Year
DEVA	28	McDonald 2	3 Year
DEVA	29	Malapi Spring D	3 Year
DEVA	30	Squaw Spring A	3 Year
DEVA	31	Mesquite Campground Spring C	3 Year
DEVA	32	Two Barrel Spring	3 Year
DEVA	33	Tjonakwie Spring	3 Year
DEVA	34	McLean Spring	3 Year
DEVA	35	Noggin Spring	3 Year
DEVA	36	Scotty's Cottonwood	3 Year

Park	GRTS	Name	Sample Type
DEVA	37	Jack 42	3 Year
DEVA	38	Young Spring	3 Year
DEVA	39	Hungry Bills Spring A	3 Year
DEVA	40	Log Spring	3 Year
DEVA	41	Jack 17	3 Year
DEVA	42	Anvil Willow	3 Year
DEVA	43	Bighorn Spring 3	3 Year
DEVA	44	Hohum Spring A	3 Year
DEVA	45	Darwin Hills Unnamed	3 Year
DEVA	46	Lost Spring	3 Year
DEVA	47	Surprise Spring NPS (formerly Surprise Spring B)	3 Year
DEVA	48	Scout Spring (West)	3 Year
DEVA	49	White Crown Spring	3 Year
DEVA	50	Wheel Spring	3 Year
DEVA	51	Lightfoot Spring	3 Year
DEVA	52	Saline Valley Marsh	3 Year
DEVA	53	Jack 09	3 Year
DEVA	54	Maidenhair Spring	3 Year
DEVA	55	Greenleaf Spring A	3 Year
DEVA	56	Brier Spring A	3 Year
DEVA	57	Jack 33	3 Year
DEVA	58	Grubstake	3 Year
DEVA	59	Wagon Spring	3 Year
DEVA	60	Hole in Rock Spring (New)	3 Year
DEVA	61	Virgin Spring B	3 Year
DEVA	62	Hawk Spring B	3 Year
DEVA	63	Bushy Seep (Upper)	3 Year
DEVA	64	Owl Spring	3 Year
DEVA	65	Miller Spring	3 Year
DEVA	66	East Tin Spring Unnamed	3 Year
DEVA	67	Cottonwood Spring	3 Year
DEVA	68	Navel Seeps (Upper)	3 Year
DEVA	69	Naghipah Spring	3 Year
DEVA	70	Waucoba 02	3 Year
DEVA	71	Hunter Spring Creek	3 Year
DEVA	72	Buckboard Spring AA	3 Year
DEVA	73	Sand Spring C	3 Year
DEVA	74	Buck Spring 1	3 Year
DEVA	75	Jayhawker Spring	3 Year

Park	GRTS	Name	Sample Type
DEVA	76	Five Mile Spring B	3 Year
DEVA	77	Lantern Spring B	3 Year
DEVA	78	Fern (Upper)	3 Year
DEVA	79	Flycatcher	3 Year
DEVA	80	Middle Snake Spring	3 Year
DEVA	81	Jack 51	Over Sample
DEVA	82	Sedge Seep E	Over Sample
DEVA	83	Upper Hall Canyon Spring	Over Sample
DEVA	84	Rabbit Brush Spring	Over Sample
DEVA	85	Jack 38	Over Sample
DEVA	86	Cow Creek Urban Spring C	Over Sample
DEVA	87	Willow Spring (LCM)	Over Sample
DEVA	88	Trigger	Over Sample
DEVA	89	Canyon Spring B (Main)	Over Sample
DEVA	90	Coyote Well	Over Sample
DEVA	91	Hobo Spring A	Over Sample
DEVA	92	Butterfly Spring	Over Sample
DEVA	93	Highison Spring	Over Sample
DEVA	94	Keane Wonder Spring Main	Over Sample
DEVA	95	Main Hanaupah Spring 1 (Uppermost)	Over Sample
DEVA	96	Shanche Spring D	Over Sample
DEVA	97	Jack 45	Over Sample
DEVA	98	White Tanks	Over Sample
DEVA	99	Jack 31	Over Sample
DEVA	100	Jubilee (Previously called Butte Valley)	Over Sample
DEVA	101	Burro Spring B	Over Sample
DEVA	102	Klare Spring	Over Sample
DEVA	103	Timpapah Spring	Over Sample
DEVA	104	Bicentennial Spring	Over Sample
DEVA	105	Bonnie Claire Seep	Over Sample
DEVA	106	Cave Rock 1	Over Sample
DEVA	107	Horseshoe	Over Sample
DEVA	108	Morning Glory Spring	Over Sample
DEVA	109	Brewery Spring	Over Sample
DEVA	110	Flowing Well	Over Sample
DEVA	111	Mill Cottonwood	Over Sample
DEVA	112	Scraper Spring B	Over Sample
DEVA	113	Dog Spring	Over Sample
DEVA	114	Black Spot Spring	Over Sample

Park	GRTS	Name	Sample Type
DEVA	115	Jack 43	Over Sample
DEVA	116	Leaning Rock Tanks	Over Sample
DEVA	117	Montgomery Spring	Over Sample
DEVA	118	Mormon Point Spring Unnamed	Over Sample
DEVA	119	Mortar Spring	Over Sample
DEVA	120	Bullfrog Spring	Over Sample
DEVA	121	Ibex Spring 2	Over Sample
DEVA	122	Hidden Spring	Over Sample
DEVA	123	Arsenic Spring	Over Sample
DEVA	124	Obsidian Seeps (A, B, C)	Over Sample
DEVA	125	Telephone Spring	Over Sample
DEVA	126	Navel Spring Again	Over Sample
DEVA	127	Thorndike Spring	Over Sample
DEVA	128	Shell Spring	Over Sample
DEVA	129	Newfound Spring	Over Sample
DEVA	130	East Salt Spring B	Over Sample
DEVA	131	Little Sand Spring A	Over Sample
DEVA	132	Woodcamp Spring	Over Sample
DEVA	133	SOSP 06	Over Sample
DEVA	134	Overlook Seep	Over Sample
DEVA	135	Pussywillow Spring	Over Sample
DEVA	136	Cottonball Marsh Sulfur Spring 1	Over Sample
DEVA	137	South Hanaupah Spring 2 Middle	Over Sample
DEVA	138	Grapevine Niblet	Over Sample
DEVA	139	Big Dodd Spring	Over Sample
DEVA	140	Monument Canyon Spring	Over Sample
DEVA	141	Widow Spring	Over Sample
DEVA	142	Cliff Spring	Over Sample
DEVA	143	Jack 22	Over Sample
DEVA	144	Russel Camp B (Previously called Jubilee)	Over Sample
DEVA	145	Quartz Spring	Over Sample
DEVA	146	Palmer Seep	Over Sample
DEVA	147	Green Spring	Over Sample
DEVA	148	Anvil Mesquite Spring	Over Sample
DEVA	149	BlackJack Spring N Main BJ	Over Sample
DEVA	150	Upper Leadfield Spring	Over Sample
DEVA	151	Burns Spring (Lower)	Over Sample
DEVA	152	Upper Warm Spring B	Over Sample
DEVA	153	Claussen Spring	Over Sample

Park	GRTS	Name	Sample Type
DEVA	154	Spider Spring C	Over Sample
DEVA	155	Quartzite Spring	Over Sample
DEVA	156	Alkali Spring	Over Sample
DEVA	157	Jack 35	Over Sample
DEVA	158	Arrastre Spring	Over Sample
DEVA	159	East Salt Flat Spring Unnamed	Over Sample
DEVA	160	Monarch Spring	Over Sample
DEVA	161	Rhodes Spring	Over Sample
DEVA	162	Willow Spring C (Gold Valley)	Over Sample
DEVA	163	Staininger Spring (5 NPS Boxes)	Over Sample
DEVA	164	Daylight Willow Spring	Over Sample
DEVA	165	Harris Hill Spring Unnamed	Over Sample
DEVA	166	Tarantula Spring	Over Sample
DEVA	167	Middle Tuber Canyon Spring	Over Sample
DEVA	168	Waucoba 04	Over Sample
DEVA	169	Table Spring C	Over Sample
DEVA	170	Wahguyhe Spring	Over Sample
DEVA	171	Jack 40 (Unnamed)	Over Sample
DEVA	172	Upper Talc Mine Spring (Arrastre in old Database)	Over Sample
DEVA	173	Falcon Seep	Over Sample
DEVA	174	Lostman Spring	Over Sample
DEVA	175	Salsberry Peak Unnamed	Over Sample
DEVA	176	Badwater Spring 5 (Main)	Over Sample
DEVA	177	Jackknife Spring	Over Sample
DEVA	178	Triangle Spring C	Over Sample
DEVA	179	Lower Tuber Spring	Over Sample
DEVA	180	Pool Spring	Over Sample
DEVA	181	Whisper Spring	Over Sample
DEVA	182	QA Spring	Over Sample
DEVA	183	Fossil Spring	Over Sample
DEVA	184	Funston Spring	Over Sample
DEVA	185	Hunter Spring	Over Sample
DEVA	186	Last Chance Springs P	Over Sample
DEVA	187	Emigrant Spring (Lower)	Over Sample
DEVA	188	Needle Spring	Over Sample
DEVA	189	Wheelbarrow Spring	Over Sample
DEVA	190	Potlicker Seep	Over Sample
DEVA	191	Schwab Spring	Over Sample
DEVA	192	Salt Creek	Over Sample

Park	GRTS	Name	Sample Type
DEVA	193	Flicker Spring	Over Sample
DEVA	194	Gargoyle Spring	Over Sample
DEVA	195	Little Dodd Spring	Over Sample
DEVA	196	Lemonade Spring	Over Sample
DEVA	197	Flores Ranch Spring	Over Sample
DEVA	198	Delfs Spring 1	Over Sample
DEVA	199	Anvil Spring	Over Sample
DEVA	200	Epipactus Spring B	Over Sample
DEVA	201	Centennial Spring	Over Sample
DEVA	202	Ranger Spring	Over Sample
DEVA	203	Marble Potholes	Over Sample
DEVA	204	Shotgun Spring A	Over Sample
DEVA	205	Stone Corral	Over Sample
DEVA	206	Lower Warm Springs B	Over Sample
DEVA	207	Mill Canyon Spring	Over Sample
DEVA	208	Tule Springs	Over Sample
DEVA	209	Drum Spring	Over Sample
DEVA	210	Tule George Spring C	Over Sample
DEVA	211	Jack 21	Over Sample
DEVA	212	Warm Spring B	Over Sample
DEVA	213	Red Rock Spring	Over Sample
DEVA	214	Bebbia Potholes	Over Sample
DEVA	215	Sheep Spring A	Over Sample
DEVA	216	Daylight Pass Spring	Over Sample
DEVA	217	Heather Spring	Over Sample
DEVA	218	Yellowjacket Spring	Over Sample
DEVA	219	Jack 06	Over Sample
DEVA	220	USGS Spring A	Over Sample
DEVA	221	Liar Spring	Over Sample
DEVA	222	Grapevine Willow Spring	Over Sample
DEVA	223	Jack 28	Over Sample
DEVA	224	Lower Talc Mine Spring	Over Sample
DEVA	225	Traderat	Over Sample
DEVA	226	Fire Spring	Over Sample
DEVA	227	Salsberry A	Over Sample
DEVA	228	Eagle Borax Works Spring	Over Sample
DEVA	229	Ramhorn Spring	Over Sample
DEVA	230	Rice's Pothole Spring	Over Sample
JOTR	1	Conejo Spring	Annual

Park	GRTS	Name	Sample Type
JOTR	2	Pinkham Spring	Annual
JOTR	3	Pete's Spring	Annual
JOTR	4	Gibbard Spring	Annual
JOTR	5	Cottonwood Palm Spring	Annual
JOTR	6	North Wall Street Spring Unnamed	Annual
JOTR	7	West Lang Ridge Spring Unnamed	Annual
JOTR	8	East Forty Nine Palms Unnamed	Annual
JOTR	9	Buzzard Spring	Annual
JOTR	10	Queen Mountain Unknown Wash Spring	Annual
JOTR	11	Dove Spring	3 Year
JOTR	12	Bare Tree Spring	3 Year
JOTR	13	Hayfield Summit Spring	3 Year
JOTR	14	Rattlesnake Oasis	3 Year
JOTR	15	Stubbe Spring	3 Year
JOTR	16	Long Canyon Shortcut Spring Unnamed	3 Year
JOTR	17	Dike Spring	3 Year
JOTR	18	Fan Hill Canyon Headwaters Unnamed	3 Year
JOTR	19	Garret Canyon Spring	3 Year
JOTR	20	Tunnel Seep	3 Year
JOTR	21	Cotton Spring	3 Year
JOTR	22	Clover Spring Complex	3 Year
JOTR	23	Samuelson Well 1 Spring	3 Year
JOTR	24	Bad Water Canyon Spring Unnamed	3 Year
JOTR	25	Buckhorn Spring and Tank	3 Year
JOTR	26	Johnson Spring	3 Year
JOTR	27	Black Rock Spring	3 Year
JOTR	28	Bolster Spring Unnamed	3 Year
JOTR	29	Meek Seep	3 Year
JOTR	30	Little Boulder Spring	3 Year
JOTR	31	Pearl Spring	3 Year
JOTR	32	Horseshoe Bend Spring Unnamed	3 Year
JOTR	33	Lost Palms Canyon Oasis	3 Year
JOTR	34	Coyote Spring	3 Year
JOTR	35	West Drainage Spring	3 Year
JOTR	36	Lone Palm Spring	Over Sample
JOTR	37	Cottonwood Spring	Over Sample
JOTR	38	Sparrow Spring	Over Sample
JOTR	39	Lone Willow Spring	Over Sample
JOTR	40	Chuckwalla Bills Spring	Over Sample

Park	GRTS	Name	Sample Type
JOTR	41	Hayfield Spring	Over Sample
JOTR	42	Willow Hole	Over Sample
JOTR	43	Burns Spring	Over Sample
JOTR	44	Rattlesnake A Spring	Over Sample
JOTR	45	Smoke Tree Tributary Seep Unnamed	Over Sample
JOTR	46	Indian Cove Wash Spring Unnamed	Over Sample
JOTR	47	Pushwalla Seep	Over Sample
JOTR	48	NW Corner Seep Unnamed	Over Sample
LAKE	41	Dripping Spring	Annual
LAKE	24	Willow Spring	Annual
LAKE	20	Horsethief Canyon	Annual
LAKE	18	Gnatcatcher Spring	Annual
LAKE	43	Pipe Springs Canyon Unnamed	Annual
LAKE	8	Rattlesnake Spring	Annual
LAKE	6	Sugarloaf Spring	Annual
LAKE	7	Corral Spring	Annual
LAKE	16	Bridge Canyon Lower Spring Unnamed	Annual
LAKE	26	Grapevine Spring AZ	Annual
LAKE	27	Monkey Cove Spring	3 Year
LAKE	11	Getchel Spring	3 Year
LAKE	37	Grapevine Spring NV	3 Year
LAKE	4	Granite Cove Spring Unnamed	3 Year
LAKE	36	Aztec Spring	3 Year
LAKE	3	Sandstone Spring	3 Year
LAKE	21	Bridge Canyon Spring	3 Year
LAKE	29	Pipe Spring	3 Year
LAKE	39	Latos Pools	3 Year
LAKE	38	Scirpus Spring	3 Year
LAKE	32	Sacatone Spring Main (Lower)	3 Year
LAKE	42	Burro Spring LAME	3 Year
LAKE	1	Salt Spring	3 Year
LAKE	31	Valley of Fire Upper Spring	3 Year
LAKE	12	Discovery Spring	3 Year
LAKE	15	Cottonwood East Spring	3 Year
LAKE	23	Rogers Bay Spring Unnamed	3 Year
LAKE	34	Cottonwood West Spring	3 Year
LAKE	-	Arizona Seep	LAKE Crew
LAKE	-	Black Canyon Spring 3 Unnamed	LAKE Crew
LAKE	-	Bighorn Sheep Spring	LAKE Crew

Park	GRTS	Name	Sample Type
LAKE	-	Nevada Hot Spring Unnamed	LAKE Crew
LAKE	-	Salt Cedar Hot Spring	LAKE Crew
LAKE	-	White Rock Canyon	LAKE Crew
LAKE	-	Boy Scout Hot Spring	LAKE Crew
LAKE	-	Lost Man Hot Spring	LAKE Crew
LAKE	-	Dawn Cold Spring	LAKE Crew
LAKE	-	Palm Tree Hot Spring A	LAKE Crew
LAKE	-	Arizona Hot Spot 1	LAKE Crew
LAKE	-	Hot Spring 1 Unnamed	LAKE Crew
LAKE	-	Arizona Hot Spot 2	LAKE Crew
LAKE	-	Sauna Cave	LAKE Crew
LAKE	-	Pupfish Hot Spring	LAKE Crew
MOJA	1	Vontrigger Spring (seep)	Annual
MOJA	2	Sacaton Spring	Annual
MOJA	3	Macedonia Spring	Annual
MOJA	4	Barnes Spring	Annual
MOJA	5	Coats Spring	Annual
MOJA	6	Holliman Spring	Annual
MOJA	7	Henry Spring qanat	Annual
MOJA	8	Willow Basin (seep #1)	Annual
MOJA	9	Talc Spring	Annual
MOJA	10	Butcher Knife Spring	Annual
MOJA	11	Willow Spring - Clark	3 Year
MOJA	12	Unnamed Spring #14	3 Year
MOJA	13	Lecyr Spring	3 Year
MOJA	14	Cedar Canyon Spring	3 Year
MOJA	15	Wild West Canyon Spring	3 Year
MOJA	16	Goldstone Spring (qanat & trough)	3 Year
MOJA	17	Eagle Well	3 Year
MOJA	18	Gold Valley Spring (collapsed qanat)	3 Year
MOJA	19	Globe Canyon Spring	3 Year
MOJA	20	Cottonwood Spring (east) - Granites	3 Year
MOJA	21	Dove Spring (qanat)	3 Year
MOJA	22	Burro Spring	3 Year
MOJA	23	Deer Spring (qanat)	3 Year
MOJA	24	Budweiser Spring (tank)	3 Year
MOJA	25	Slaughterhouse Spring (drip in trough)	3 Year
MOJA	26	Clark (between mid and upper)	3 Year
MOJA	27	Twin Spring	3 Year

Park	GRTS	Name	Sample Type
MOJA	28	Domingo Spring (old qanat & springbox)	3 Year
MOJA	29	Castle Peak Spring	3 Year
MOJA	30	Silver Lead Spring (qanat)	3 Year
MOJA	31	Granite Canyon Spring	3 Year
MOJA	32	Unnamed Spring #13	3 Year
MOJA	33	Hackberry-South Spring (pipe)	3 Year
MOJA	34	Black Diamond Spring	3 Year
MOJA	35	Sheep Spring	3 Year
MOJA	36	Ruff Spring	3 Year
MOJA	37	Indian Spring (Castle Peaks)	3 Year
MOJA	38	Fourth of July Canyon Creek	3 Year
MOJA	39	Dripping Spring	3 Year
MOJA	40	Crystal Spring	3 Year
MOJA	41	Live Oak Canyon Spring	3 Year
MOJA	42	Mid Hills Spring East Fork	3 Year
MOJA	43	Unnamed Spring #30	3 Year
MOJA	44	Desert Spring (dam source)	3 Year
MOJA	45	Kessler Spring (original shallow well)	3 Year
MOJA	46	Silver Lead Spring	Over Sample
MOJA	47	Horse Hills Spring	Over Sample
MOJA	48	Blind Spring	Over Sample
MOJA	49	Oak Spring	Over Sample
MOJA	50	Matt Spring	Over Sample
MOJA	51	Marl Spring (trough)	Over Sample
MOJA	52	Willow Spring - Granites	Over Sample
MOJA	53	Taylor Spring	Over Sample
MOJA	54	Bathtub Spring MH (trough)	Over Sample
MOJA	55	Black Bird Mine Spring	Over Sample
MOJA	56	Finger Rock Spring	Over Sample
MOJA	57	Mail Spring	Over Sample
MOJA	58	Cedar Canyon Narrows Spring	Over Sample
MOJA	59	Coyote Springs - Granites (#3)	Over Sample
MOJA	60	Warm Springs (seep in wash)	Over Sample
MOJA	61	White Rock	Over Sample
MOJA	62	Wild Cat Spring	Over Sample
MOJA	63	Van Winkle Spring	Over Sample
MOJA	64	Quail Spring	Over Sample
MOJA	65	Barnwell Seep	Over Sample
MOJA	66	Chicken Water Spring	Over Sample

Park	GRTS	Name	Sample Type
MOJA	67	Arrowweed Spring	Over Sample
MOJA	68	Winston Basin # 2 (pool above)	Over Sample
MOJA	69	Juniper Spring	Over Sample
MOJA	70	Rock Spring	Over Sample
MOJA	71	Whisky Spring (Clark)	Over Sample
MOJA	72	Cornfield Spring	Over Sample
MOJA	73	Keystone Spring	Over Sample
MOJA	74	Live Oak Spring (lower qanat - tunnel)	Over Sample
MOJA	75	Falls Canyon Spring - Upper (East Fork) (above)	Over Sample
MOJA	76	Cave Spring (trough)	Over Sample
MOJA	77	Cut Spring (unnamed spring 4)	Over Sample
MOJA	78	Mexican Water (qanat)	Over Sample
MOJA	79	Unnamed Spring #27	Over Sample
MOJA	80	Blind Spring West	Over Sample
MOJA	81	Carruthers Canyon (top)	Over Sample
MOJA	82	Woods Mountain Spring	Over Sample
MOJA	83	Cane Spring west	Over Sample
MOJA	84	Unnamed Spring #26	Over Sample
MOJA	85	Malpais Springs (upper)	Over Sample
MOJA	86	Cabin Spring #4	Over Sample
MOJA	87	Unnamed USGS Spring Clark 2	Over Sample
MOJA	88	Providence Mill Site Seep	Over Sample
MOJA	89	Wayne's Spring	Over Sample
MOJA	90	Cottonwood Spring MH (springbox source)	Over Sample
MOJA	91	Colosseum Gorge Seep	Over Sample
MOJA	92	Whisky Spring	Over Sample
MOJA	93	Lance Spring	Over Sample
MOJA	94	Twin Buttes Spring	Over Sample
MOJA	95	Bolder Spring	Over Sample
MOJA	96	Mine Spring	Over Sample
MOJA	97	Cliff Canyon Spring - upper	Over Sample
MOJA	98	Columbia Mine Spring	Over Sample
MOJA	99	Cove Spring	Over Sample
MOJA	100	Piute Spring	Over Sample
PARA	1	Coyote Spring	Annual
PARA	2	Lime Kiln Canyon Spring A	Annual
PARA	3	Mustang Spring B	Annual
PARA	4	UV39	Annual
PARA	5	Lower Spring	Annual

Park	GRTS	Name	Sample Type
PARA	6	Jump Canyon Lower Spring A	Annual
PARA	7	Link Spring	Annual
PARA	8	Cedar Spring (NPS)	Annual
PARA	9	Little Arizona Spring	Annual
PARA	10	Ide Valley Spring B	Annual
PARA	11	Yellowstone Spring D	3 Year
PARA	12	Green Spring	3 Year
PARA	13	Red Rock Spring	3 Year
PARA	14	Paiute Wilderness Spring A	3 Year
PARA	15	Maple Spring B	3 Year
PARA	16	Lava Spring	3 Year
PARA	17	Pigeon Canyon Upper Spring B	3 Year
PARA	18	Cedar Spring A	3 Year
PARA	19	Burro Spring BLM	3 Year
PARA	20	Frog Spring	3 Year
PARA	21	Gyp Wash Spring	3 Year
PARA	22	Cottonwood Upper Spring B	3 Year
PARA	23	Gordon Spring E	3 Year
PARA	24	Mud Spring NPS	3 Year
PARA	25	Cockscomb Spring	3 Year
PARA	26	Ide Valley Lower West Spring	3 Year
PARA	27	Last Chance Cliffside Spring C	3 Year
PARA	28	Ambush Waterpockets	3 Year
PARA	29	Cove Spring South B	3 Year
PARA	30	Pocum Cove Spring C	3 Year
PARA	31	Little Wolf South Spring	3 Year
PARA	32	Mt. Logan Spring A	3 Year
PARA	33	Pigeon Canyon Lower Spring	3 Year
PARA	34	White Saddle Spring A	3 Year
PARA	35	Ed Spring	3 Year
PARA	36	Cupe Spring	3 Year
PARA	37	Grapevine Spring	3 Year
PARA	38	Pocum Wash Spring C	3 Year
PARA	39	Hidden Spring A	3 Year
PARA	40	Dansill Canyon West Spring	3 Year
PARA	41	Chill Heal Spring	3 Year
PARA	42	Pocum Cove Upper Spring A	3 Year
PARA	43	Dew Drop Spring B	3 Year
PARA	44	Orsen-White Spring	3 Year

Park	GRTS	Name	Sample Type
PARA	45	South Virgin Ridge Spring B	3 Year
PARA	46	Sand Spring	Over Sample
PARA	47	Schultz Spring	Over Sample
PARA	48	Cold Spring	Over Sample
PARA	49	Andrus Upper Spring	Over Sample
PARA	50	Cane Spring A	Over Sample
PARA	51	Rattlesnake Spring A	Over Sample
PARA	52	UV45	Over Sample
PARA	53	Black Willow Spring B	Over Sample
PARA	54	Ide Valley West Spring A	Over Sample
PARA	55	Last Chance Canyon Lower Spring B	Over Sample
PARA	56	Cane Spring NPS	Over Sample
PARA	57	Burro Spring NPS	Over Sample
PARA	58	Paiute Wilderness South Spring C	Over Sample
PARA	59	Salt Spring	Over Sample
PARA	60	Coyote Spring Mt. Trumbull	Over Sample
PARA	61	Middle Spring B	Over Sample
PARA	62	Mud Spring	Over Sample
PARA	63	Grassy Spring	Over Sample
PARA	64	Death Valley Pond Spring	Over Sample
PARA	65	Mud Mountain East Spring D	Over Sample
PARA	66	Death Valley Spring	Over Sample

Appendix B. Power Analysis Report

POWER ANALYSIS FOR TREND DETECTION IN DESERT SPRINGS PARAMETERS FOR THE MOJAVE DESERT NETWORK

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INTRODUCTION

The Mojave Desert Network (MOJN) of the National Park Service (NPS) identified desert springs as a vital sign for long-term monitoring. Vital signs are indicators of park ecosystem condition, stressors, or value. Indicators for MOJN desert springs, such as water availability and ecological condition, will be monitored over time at the following five parks within MOJN: Death Valley National Park (DEVA), Joshua Tree National Park (JOTR), Lake Mead National Recreation Area (LAKE), Mojave Desert National Preserve (MOJA), and Grand Canyon-Parashant National Monument (PARA).

The power of a statistical hypothesis test is the probability that the null hypothesis is rejected when the alternative hypothesis is true (Cohen 1988). The power to detect a trend is the probability that a trend test at a given alpha level is statistically significant. The power to detect trend depends on the Type I error rate (here, $\alpha = 0.10$), the magnitude of the trend, and the variance in the trend estimate. A power analysis is a statistical tool to assess the performance of a proposed trend test. The results of the power analysis can inform the monitoring design before implementation (Sims et al. 2006). This power analysis will examine pilot data for two desert spring indicators and assess the ability of the proposed sample sizes of springs to detect trends in spring permanence and tamarisk prevalence over monitoring periods of 12 to 30 years.

The target population consists of 494 springs and spring complexes (a set of springs fed by the same source) within park boundaries that were not monitored as part of another vital sign protocol, and were not manipulated, diverted, or 100% contained. The proposed membership design is a spatially-balanced generalized random tessellation stratified (GRTS) sample of springs with stratification by park. Using a spatially-balanced design reduces the probability that more than one spring in a spring complex will be selected, so this clustering will not introduce an additional level of correlation among sampled springs.

METHODS

Two binary data types are examined in this report: the prevalence of tamarisk and the permanence of springs in the population. Tamarisk presence/absence data were recorded at 64 springs in the five parks during at least 3 survey years occurring in 2005, 2006, 2011, 2012, and 2013. Spring permanence data, measured as presence or absence of water at a spring, were collected from 2004 to 2012 at 238 springs in MOJA. These data were collected by volunteer observers in a citizen science program and used as an indicator of year-round water, or spring permanence. The observed proportions of springs with tamarisk and with water are shown in Figures 1 and 2, respectively.

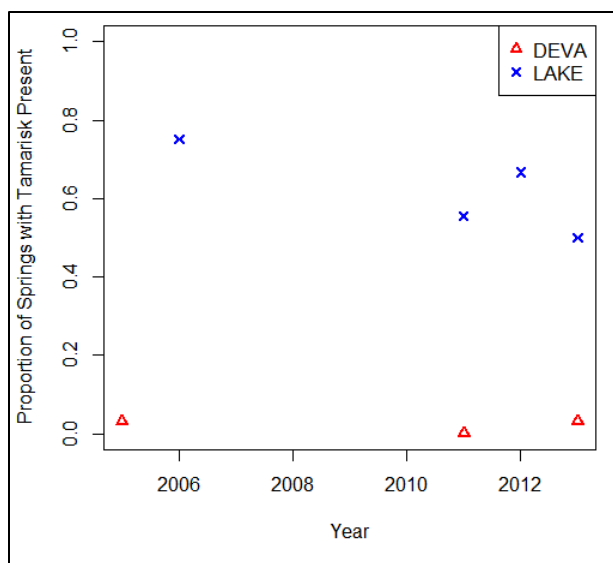


Figure 1. Observed proportion of DEVA and LAKE springs with tamarisk present.

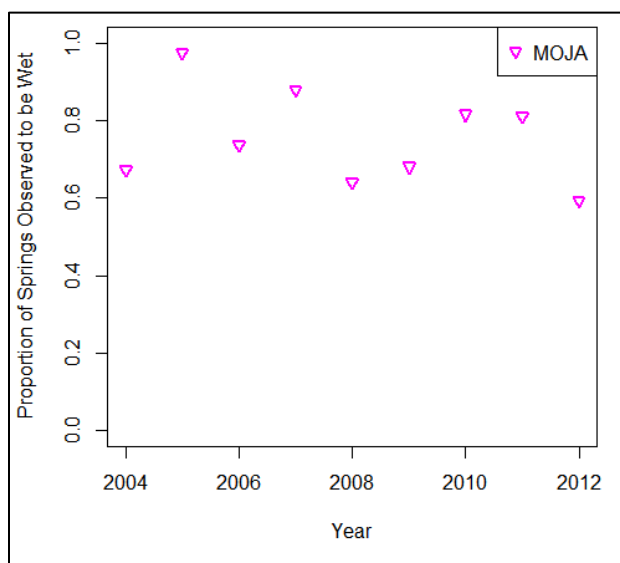


Figure 2. Proportion of MOJA springs observed to be wet by year.

The selected springs will be visited with an augmented serially-alternating revisit design. Define a panel as a set of springs always visited in the same year. Using the notation of McDonald (2003), the [(1-0), (1-2)] augmented serially-alternating revisit design within each park consists of one panel of springs visited each year and never rested (1-0) and one panels of springs that are visited one year then rested for two years (1-2). The annual panel will consist of 10 springs per park that are visited every year. The serially-alternating panels for each park contain 25, 35, or 60 springs (Table 1). The network-level number of springs visited each year will total about 120 springs. In this power analysis, the number of years needed to detect trends of particular magnitudes for these proposed sample sizes will be examined.

Table 1. MOJN desert springs revisit design.

Park	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
DEVA	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
DEVA	–	60	–	–	60	–	–	60	–	–	60	–	–	60	–	–	60	–
JOTR	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
JOTR	–	–	25	–	–	25	–	–	25	–	–	25	–	–	25	–	–	25
LAKE	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
LAKE	25	–	–	25	–	–	25	–	–	25	–	–	25	–	–	25	–	–
MOJA	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
MOJA	–	–	35	–	–	35	–	–	35	–	–	35	–	–	35	–	–	35
PARA	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
PARA	35	–	–	35	–	–	35	–	–	35	–	–	35	–	–	35	–	–
TOTAL	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120

Trend analysis

Spring permanence was modeled from a 9-year time series of 238 springs. Tamarisk prevalence was collected from 64 springs over 5 unique years. Because both data sets have binary outcomes, the binomial family GLMM is used to model trend. The trend analysis was conducted in the R (2015) software environment with the *lme4* (Bates et al. 2014) R package. The fully specified model includes a spring-level intercept, a spring-level slope, and a year-level intercept as a corollary to the Piepho and Ogutu (2002) model.

Power simulation

For each outcome of interest, Monte Carlo simulation was used to generate random samples of data reflecting the mean and variance structure of the pilot data and exhibiting a known annual trend. The annual trend is the proportional increase or decrease in the occupancy rate each year. For example, an annual 2% decrease is represented by $p = -0.02$.

For simulations of 1,000 iterations each, a population was generated for a given baseline status (estimated as the mean prevalence or permanence in the final year of the pilot data), the estimated random effects (if applicable), monitoring period lengths of 12 to 30 years, and trends (p) of 2%, 4%, or 6% annually. For each iteration of the LAKE tamarisk prevalence and MOJA spring permanence power analyses, trend was randomly assigned to be increasing or decreasing since a two-sided test of trend in either direction was of interest for these indicators. Tamarisk prevalence in DEVA was low, and it is difficult to detect declining trends in small prevalences, so only increasing trends were examined with a one-sided trend test for an increasing prevalence rate. For each simulated population, samples of specified sizes were randomly selected and the [(1-0), (1-2)] revisit design was imposed using the park-level sample allocation across panels provided in Table 1.

The binomial GLMM with random effects for spring and year was used to estimate trend spring permanence and the two tamarisk prevalence outcomes. Trend tests were conducted at the $\alpha = 0.10$ level. Trend test size and test power were assessed in the power simulation. Test size was obtained as the proportion of iterations for which the null hypothesis of no trend was rejected at the 0.10 level when no trend was simulated. Similarly, test power was estimated by the proportion of iterations for which the null hypothesis was rejected when a non-zero trend was simulated.

RESULTS

Trend analysis

MOJA spring permanence was modeled with a binomial GLMM, and random effects for spring-to-spring variation and year-to-year variation were estimated (Table 2). Trend models that included the random-slope variance resulted in errors indicating model over-parameterization, so the random slope term was omitted from all models. No significant trend was detected at the 0.10 level (slope = -0.2049, SE = 0.1269, p-value = 0.1060). Spring permanence for the final year of the pilot data set was estimated as 0.78 (90%-CI: 0.56, 0.90). This estimate will serve as the baseline status for the power simulation.

Initial modeling of tamarisk prevalence was based on the combined data set from all parks. Park-level fixed effects were examined for the tamarisk prevalence data, but low prevalence in all parks

except LAKE resulted in a high estimate of spring-to-spring variation. To increase model stability and measure within-park variability among springs, tamarisk prevalence was modeled by park for a high-prevalence population (LAKE) and a low-prevalence population (DEVA).

Estimates of spring-to-spring and year level random effects were zero for the LAKE tamarisk prevalence data set (Table 2), so standard logistic regression was used for this outcome. No significant trend in LAKE tamarisk prevalence was detected at the 0.10 level (slope = -0.1451, SE = 0.1540, p-value = 0.3460). The LAKE tamarisk prevalence rate for the final year of pilot data was estimated as 0.52 (90%-CI: 0.28, 0.74).

A model of DEVA tamarisk prevalence was obtained with a large spring-to-spring variance estimate of 122, but the results from this model proved problematic in simulation due to prevalence probabilities near zero. Therefore, the final model of tamarisk prevalence in DEVA was a generalized linear model that did not include random effects (Table 2). The estimated trend of -0.0567 (SE = 0.2035) was not significant at the 0.10 level (p-value = 0.7805). The DEVA tamarisk prevalence rate for the final year of pilot data was estimated as 0.02 (90%-CI: 0.003, 0.10).

Table 2: Trend analysis results.

Outcome	Intercept	Slope	Trend test z-statistic (p-value)	Spring-to- spring variation	Year-to-year variation
Tamarisk Prevalence (LAKE)	1.2225 (0.9211)	-0.1451 (0.1540)	-0.942 (0.3460)	0	0
Tamarisk Prevalence (DEVA)	-3.6038 (1.0857)	-0.0567 (0.2035)	-0.279 (0.7805)	0	0
Spring Permanence (MOJA)	2.8814 (0.6610)	-0.2049 (0.1269)	-1.615 (0.1060)	4.3630	0.7802

Power simulation

For the spring prevalence power analysis, the population was randomly generated from both the estimated fixed effects and the random effects variance components. The tamarisk trend models did not include random effects, so the baseline status of each spring in the simulated populations was generated from a normal distribution with mean equal to the estimated intercept term and standard error equal to the estimated intercept standard error. This randomization generated a non-zero spring-to-spring variance component estimated in the power analysis with the GLMM.

The trend test size was estimated as the proportion of times the null hypothesis of no trend was erroneously rejected (Table 3). Trend test size was 0.165 for trend tests of spring permanence monitored over 12 years but improved to 0.132 as the monitoring period increased to 30 years. For the two tamarisk prevalence outcomes, test size ranged from 0.083 to 0.098, attaining nearly-nominal rates of 0.10.

Table 3. Trend test size for two data types (for tests conducted at $\alpha = 0.10$).

Monitoring period (years)	Spring Permanence (MOJA)	Tamarisk Prevalence (LAKE)	Tamarisk Prevalence (DEVA)
12	0.165	0.093	0.094
18	0.154	0.086	0.098
24	0.140	0.083	0.096
30	0.132	0.091	0.083

The power to detect trends in MOJA spring permanence for an annual sample of 10 springs and a single serially-alternating panel of 35 springs exceeds 0.80 for an annual increasing or decreasing trend of 2% after 24 to 30 years, after 18 to 24 years for annual trends of 4%, and after 12 to 18 years for trend of 6% in either direction (Table 4, Figure 3). Despite the relatively high year-to-year variation, adequate power to detect trends in spring permanence is obtained within 18 to 30 years. The power to detect annual trends in LAKE tamarisk prevalence with an annual sample of 10 springs and a single serially-alternating panel of 25 springs benefits even more dramatically from a longer monitoring period. Trends of 2%, 4%, and 6% in either direction may be detected at the 0.10 level with power of at least 0.8 after 24 years (Table 4, Figure 4). Power to detect an annual increasing trend of 2% in DEVA tamarisk prevalence with an annual sample of 10 springs and a single serially-alternating panel of 60 springs does not achieve 0.8 within 30 years, but larger trends of 4% and 6% may be detected at the 0.10 level within 30 and 24 years, respectively (Table 4, Figure 5).

Table 4. Power to detect trends at the 0.10 level for MOJA spring permanence and tamarisk at LAKE and DEVA for a range of monitoring periods and annual trends.

Outcome	Monitoring period (years)	2% annual trend	4% annual trend	6% annual trend
Spring Permanence (MOJA)	12	0.440	0.693	0.735
	18	0.680	0.788	0.860
	24	0.765	0.913	0.943
	30	0.850	0.974	0.969
Tamarisk Prevalence (LAKE)	12	0.293	0.663	0.866
	18	0.636	0.930	0.997
	24	0.889	0.983	0.998
	30	0.975	0.976	1.000
Tamarisk Prevalence (DEVA)	12	0.151	0.213	0.313
	18	0.237	0.425	0.726
	24	0.298	0.715	0.966
	30	0.484	0.935	0.999

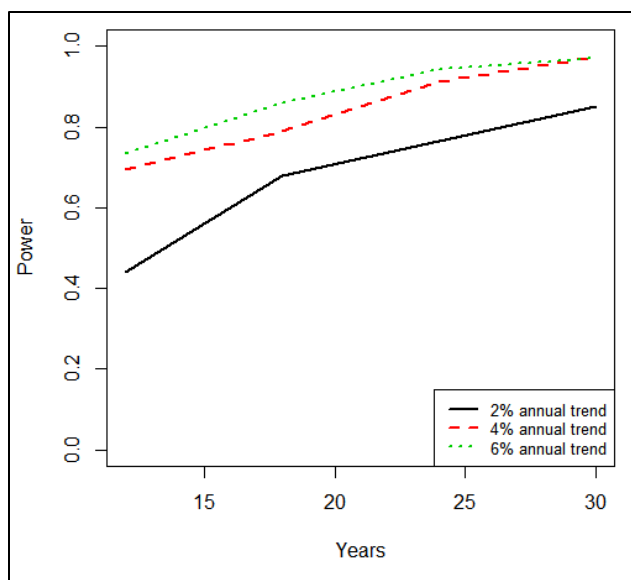


Figure 3. Power to detect 2%, 4%, and 6% annual increasing or decreasing trends in MOJA spring permanence over a range of monitoring periods with a two-sided test at the 0.10 level.

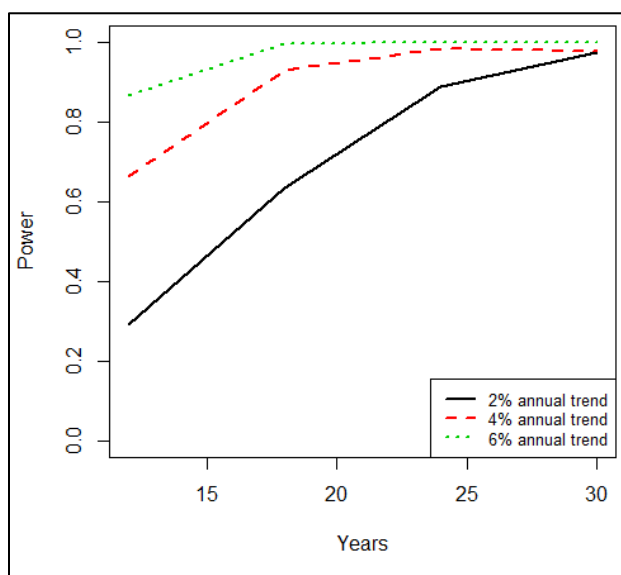


Figure 4. Power to detect 2%, 4%, and 6% annual increasing or decreasing trends in LAKE tamarisk prevalence over a range of monitoring periods with a two-sided test at the 0.10 level.

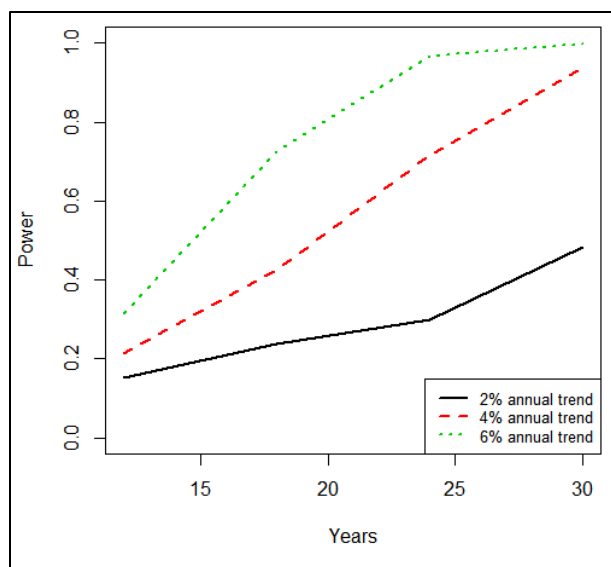


Figure 5. Power to detect 2%, 4%, and 6% annual increasing trends in DEVA tamarisk prevalence over a range of monitoring periods with a one-sided test for an increase at the 0.10 level.

DISCUSSION

A power analysis based on results from trend analyses of MOJN spring prevalence and tamarisk prevalence pilot data is used to assess the proposed sample sizes for each park. The results of the power analysis indicate that proposed sample sizes yield adequate power to detect annual trends of 4% to 6% within 30 years, and a 2% annual trend may be detected in MOJA spring permanence and LAKE tamarisk prevalence within 30 and 24 years, respectively.

Spring permanence was modeled from a 9-year time series of 238 springs which provided a better basis for estimating random effects. The tamarisk prevalence data set was collected from only 9 LAKE springs and 32 DEVA springs over 5 unique years. Low annual variation is expected for an indicator of presence of a tree species, but the estimate of zero year-to-year variation for tamarisk prevalence in both parks may be an artifact of data sparsity rather than an indicator of precision.

Two reasons may contribute to the higher power observed for trends in spring permanence than in tamarisk prevalence. First, the baseline spring permanence rate was estimated to be about 0.77, so a proportional trend for spring permanence represents a larger annual change than for the low DEVA tamarisk prevalence of 0.02. Second, trend test size for spring permanence is inflated, with the higher test size observed for shorter monitoring periods (Table 3). The higher-than-nominal test size observed for spring permanence is likely due to the large estimate of year-to-year variation obtained for spring permanence.

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