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Springs, Seeps and Tinajas Monitoring Protocol

Chihuahuan and Sonoran Desert Networks

Natural Resource Report NPS/SOPN/NRR—2018/1796

ON THE COVER

Springs monitoring. NPS Photo by J. Miller

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Acronyms and Abbreviations

CHDN:	Chihuahuan Desert Network
FGDC:	Federal Geographic Data Committee
GIS:	geographic information systems
GPS:	global positioning system
I&M:	inventory and monitoring
NHS:	national historic site
NM:	national monument
NMem:	national memorial
NP:	national park
NPS:	National Park Service
NRA:	national recreation area
QA/QC:	quality assurance/quality control
SOP:	standard operating procedure
SWNC:	Southwest Network Collaboration
WSR:	wild and scenic river

Abstract

Springs, seeps, and tinajas are relatively rare but ecologically important natural resources in the American Southwest. Monitoring arid-land springs provides information on several high-priority vital signs in Chihuahuan Desert and Sonoran Desert network parks, including water quantity, water quality, and invasive non-native plants. The overall goal of arid-land springs monitoring is to detect broad-scale changes in aquatic and riparian ecological condition by observing selected drivers, stressors and processes. Monitoring is conducted at “sentinel springs” (a targeted design) once per year in the vernal (spring) season. This protocol describes four modules (water quantity, water quality, site condition, and site characterization), with a core set of minimum parameters that monitor the status and long-term trends of spring, seep and tinaja ecosystems. Data are collected on persistence of springs, spring discharge, wetted extent, core water quality parameters, water chemistry, disturbance, obligate/facultative wetland plants, invasive non-native plants and wildlife, spring type, and descriptions/documentation of the spring site.

This protocol outlines the background, objectives and methods for long-term monitoring of arid-land springs in National Park Service units of the Chihuahuan Desert and Sonoran Desert networks. The protocol narrative describes the (1) background information on springs and the monitoring program, (2) monitoring goals and objectives, (3) sampling design, (4) field methods, (5) data management, (6) reporting and analysis, (7) personnel requirements and training, (8) operational requirements, and (9) procedures for revising the protocol. The ten standard operating procedures (SOPs) that describe the details of the protocol (preparation, field methods, data management) are electronically available at the National Park Service’s Integrated Resource Management Applications portal.

Acknowledgments

The Chihuahuan Desert and Sonoran Desert networks springs monitoring protocol builds on inventory methods developed by Don Sada and Karl Pohlmann of the Desert Research Institute. In particular, Don Sada was critical to the development of this protocol. Staff from network parks provided valuable feedback; in particular, Don Swann and Jeffrey Bennett provided key insights. Staff from the National Park Service Mojave Desert, Northern Colorado Plateau and Southern Colorado Plateau networks, along with staff from the U.S. Forest Service Groundwater Dependent Ecosystem Monitoring Development Team, participated in a workshop with the Chihuahuan Desert and Sonoran Desert networks that informed this protocol. Staff from the five inventory and monitoring networks also participated in the development of a database framework that was valuable for aligning protocols among the networks. Steve Monroe (Southern Colorado Plateau Network) and Rebecca Weissinger (Northern Colorado Plateau Network) deserve special thanks for their development of monitoring protocols for springs, riparian systems and water quality in the region. Steve Buckley, Dana Backer, Sarah Studd and Jesper Devantier worked to develop procedures for monitoring vegetation that were ultimately not included. Sarah Studd expanded our list of obligate/facultative vegetation and was a valuable sounding board during protocol development. Keith Sauter and Mary Levandowski were critical to developing standard operating procedures and datasheets for springs monitoring and Lindsay Smythe improved our decontamination procedures. In addition, numerous field crew members of collected data for inventory and pilot monitoring efforts and helped identify areas that needed clarification. Rebecca Weissinger and Nicole Hupp provided a thoughtful review and helpful suggestions. Park staff from both networks ensured that our crews were safe and supported during field efforts.

Version 1.00

Revision History Log

Previous version#	Revision date	Author	Changes made	Reason for change	New version #
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1. Background

The core mission of the National Park Service (NPS), as outlined in the agency's 1916 Organic Act, is to protect and conserve natural and cultural resources for future generations. Responding to criticism that it lacked basic knowledge of natural resources within parks, the NPS initiated the Inventory and Monitoring (I&M) Program to detect long-term changes in physical and biological resources (NPS 1992). Parks with significant natural resources were assigned to one of 32 monitoring networks, each based on ecological similarity and geographic proximity.

This monitoring protocol applies to two I&M networks in the American Southwest: the Chihuahuan Desert Network (CHDN) and the Sonoran Desert Network (SODN), located in the Intermountain Region of the National Park Service. The Chihuahuan Desert and Sonoran Desert networks are part of the Southwest Network Collaboration (SWNC), a partnership aimed to increase effectiveness and efficiency across networks. The Southern Plains Network is also a partner in the Southwest Network Collaboration but is not implementing this protocol.

The Chihuahuan Desert Network encompasses seven park units in southeastern New Mexico and west Texas. The Chihuahuan Desert Network will conduct springs, seeps and tinajas monitoring in five parks: Amistad National Recreation Area (NRA), Big Bend National Park (NP), Carlsbad Caverns NP, Guadalupe Mountains NP, and White Sands National Monument (NM) (Figure 1). Fort Davis National Historic Site (NHS) and Rio Grande Wild and Scenic River (WSR) may be added to the monitoring protocol in the future but are not included in the initial implementation.

The Sonoran Desert Network includes 11 parks in southern Arizona and New Mexico, of which nine parks are included in this protocol: Chiricahua NM, Coronado National Memorial (NMem), Fort Bowie NHS, Gila Cliff Dwellings NM, Montezuma Castle NM, Organ Pipe Cactus NM, Saguaro NP, Tonto NM, and Tuzigoot NM. Casa Grande Ruins NM and Tumacácori National Historical Park (NHP) do not contain perennial springs (Figure 1).

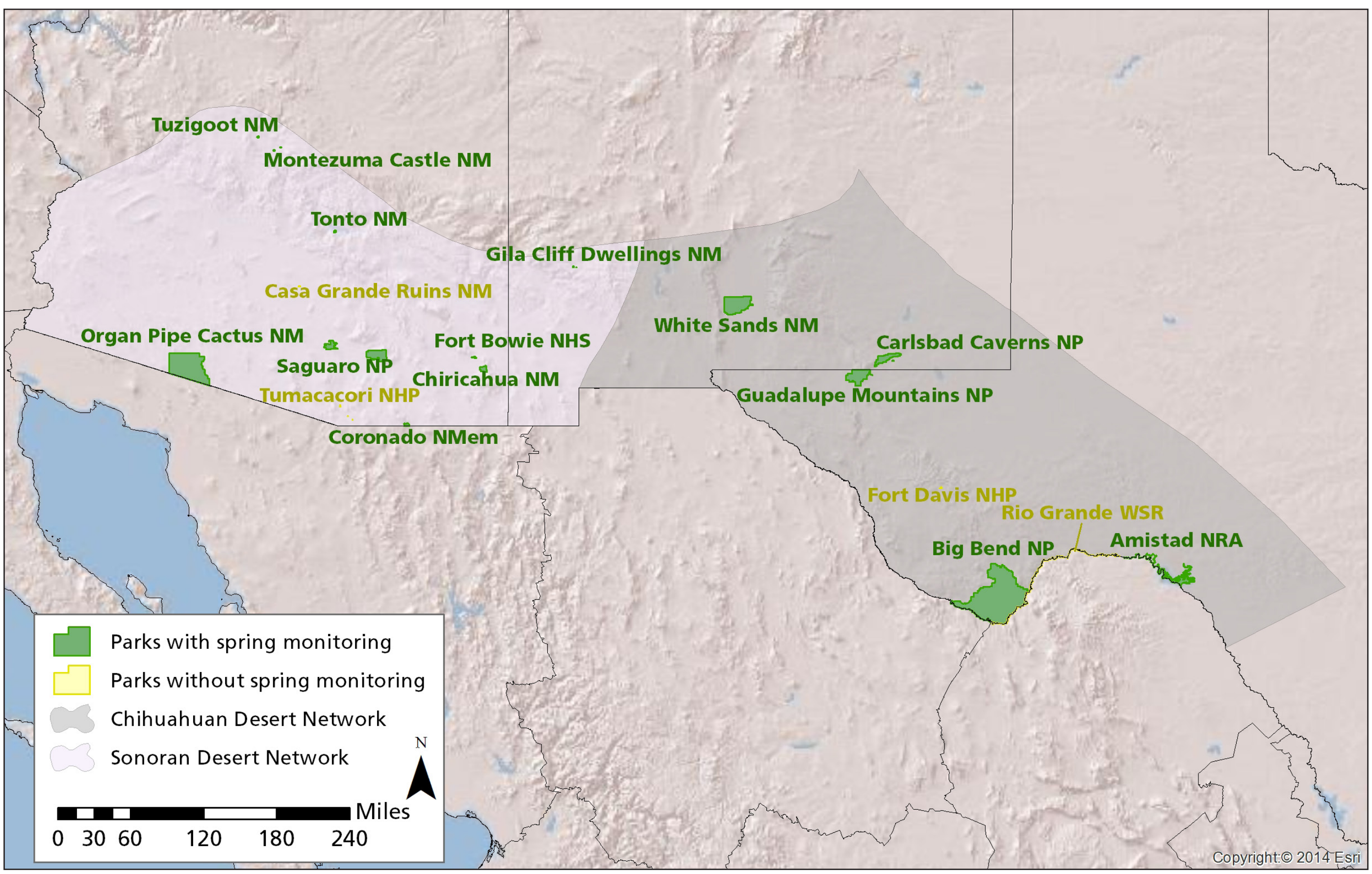

Figure 1. Chihuahuan Desert and Sonoran Desert network parks with springs monitoring

The Chihuahuan and Sonoran Desert networks completed individual monitoring plans that identified "vital signs," or monitoring parameters, representing a diverse range of natural resources, including air, water, climate, soils, plants, invertebrates and vertebrates (Mau-Crimmins et al. 2005, NPS CHDN 2010). Vital signs within each of these categories were chosen by work groups that consisted of park managers as well as regional and national experts. The work groups evaluated high-priority issues and identified candidate vital signs based on ecological significance, feasibility, and relevance to management (Mau-Crimmins et al. 2005; NPS CHDN 2010). Most of the vital signs related to spring ecosystems are common to both networks, although they use slightly different names and/or level of detail in their vital sign nomenclature (Table 1).

Additional vital signs considered, but not included in this protocol due to repeatability concerns and/or cost, include aquatic macroinvertebrates and algae, fish community dynamics, vegetation life form abundance, vegetation community structure from the Sonoran Desert Network monitoring plan (Mau-Crimmins et al. 20050) and aquatic invertebrates from the Chihuahuan Desert Network monitoring plan (NPS CHDN 2010). The vital signs included in this springs protocol are organized into three modules (water quantity, water quality and site condition) with an additional module (site characterization) that provides context for understanding change in the vital signs. Although the networks initially identified somewhat different vital signs, the modules in this protocol are implemented identically in both networks.

This monitoring protocol consists of this protocol narrative, data quality standards (McIntyre et al. 2018), and the following standard operating procedures (SOPs), available at https://irma.nps.gov/DataStore/Reference/Profile/2257331.

- SOP 1 – Safety
- SOP 2 – Personnel and training
- SOP 3 – Site characterization
- SOP 4 – Photo points
- SOP 5 – Site condition
- SOP 6 – Water quality
- SOP 7 – Water quantity
- SOP 8 – Decontamination
- SOP 9 – Data management
- SOP 10 – Revising the protocol

1.1 Spring Ecosystems as a Focus for Monitoring Efforts

"Springs ecosystems are among the most structurally complicated, ecologically and biologically diverse, productive, evolutionarily provocative, and threatened ecosystems on earth. Springs are sacred places to almost all cultures, particularly those in arid regions. Humans have used springs for water, habitat, and hunting sites throughout our evolutionary existence." (Stevens and Meretsky 2008, p. 3)

Spring ecosystems are small, relatively rare 'biodiversity hot spots' in arid lands, and aquatic organisms, riparian vegetation, and associated fauna can vary greatly by spring type (Sada et al. 2005). Springs can provide wildlife and humans with reliable sources of water (Sada and Pohlmann 2007). Arid-land springs are sparsely distributed on the landscape and are critical to the persistence of native biota, including many endemic species (Stevens and Meretsky 2008). In the American Southwest, these ecosystems historically supported a substantial proportion of aquatic, riparian and terrestrial species (Myers and Resh 1999). The isolation and persistence

Table 1. Vital signs related to springs, seeps and tinajas (shown with corresponding monitoring modules), Chihuahuan Desert (NPS CHDN 2010) and Sonoran Desert (Mau-Crimmins et al. 2005) networks.

Protocol Module	Chihuahuan Desert Network Vital Signs	Sonoran Desert Network Vital Signs
1. Water Quantity	Surface water dynamics Persistence of springs	Surface water dynamics
2. Water Quality	Surface Water Quality	Water quality (core parameters)
3. Site Condition	Invasive/non-native plants	Exotic plants status and trends
4. Site Characterization	None	None

of springs results in species endemism at some springs (Stevens and Meretsky 2008). Thus, the ecological importance of springs is greatly disproportionate to their spatial extent (Schmitz et al. 2007).

Figure 2. Example of tinajas in the Sonoran Desert Network

This protocol uses the term "arid-land spring" or "spring" to refer to all springs, seeps and tinajas monitored by Sonoran Desert and Chihuahuan Desert networks, regardless of flow or morphology, but difference exist between these types of water sources. Springs have measurable flow (or depth) (Weissinger et al. 2017). In contrast, seeps are groundwater-dependent but do not have measurable flow (Weissinger et al. 2017) and dry frequently (Sada and Pohlmann 2006). Tinajas (Figure 2), or "jars" in Spanish, are perennial and quasi-perennial surface waters found in naturally-occurring bedrock catchments (Bryan 1920; Brown and Johnson 1983) and are fed by groundwater and/or precipitation (Colbert and Swann 2015). While the term "tinaja" is commonly used in the American Southwest, a variety of terms are used to describe these natural bedrock depressions such as pothole, natural tank, plunge pool, water pocket and sand tank (Elston 1917; Bryan 1920; Brown and Johnson 1983).

A wide variety of spring, seep, and tinaja types exists in the American Southwest (Table 2; Springer and Stevens 2009; Bryan 1920; Brown and Johnson 1983). These types include rheocrene springs that fill downstream channels or "brooks," limnocrene springs that feed pools, heleocrene springs that support marshes ("ciénegas" in Spanish) and "hanging gardens" (Figure 3) that are spring- or seep-fed plant colonies that grow on cliff-faces or in alcoves where water emerges along contacts or rock fractures (Springer and Stevens 2009).

Tinajas within stream channels are formed over time by scouring fluvial processes (Bryan 1920), while tinajas outside of stream channels are formed by in situ weathering and erosion processes (Bryan 1923). Although not all tinajas are groundwater-fed, they are included in this protocol with seeps and springs because some perennial tinajas are groundwater-dependent and provide important surface water and aquatic environments in a similar fashion to springs (Brown and Johnson 1983).

Aquifer characteristics (size and location, which influence flow rate and residence time of water)

Figure 3. Example of hanging garden in the Chihuahuan Desert Network.

Table 2. Definitions of spring types (from Springer and Stevens 2009). Tinaja definition from Bryan (1920) and Brown and Johnson (1983).

Spring Type	Definition
Cave	Emergence in a cave in mature to extreme karst with sufficiently large conduits
Exposure	Cave, rock shelter fractures, or sinkholes where an unconfined aquifer is exposed near the land surface
Fountain	Artesian fountain with pressurized CO_2 in a confined aquifer
Geyser	Explosive flow of hot water from confined aquifer
Gushet	Discrete source flow gushes from a cliff wall of a perched, unconfined aquifer
Hanging garden	Dripping flow emerges usually horizontally along a geologic contact along a cliff wall of a perched, unconfined aquifer
Helocrene	Emerges from low gradient wetlands; often indistinct or multiple sources seeping from shallow, unconfined aquifers
Hillslope	Emerges from confined or unconfined aquifers on a hillslope (30-60° slope); often indistinct or multiple sources
Hypocrene	A buried spring where flow does not reach the surface, typically due to very low discharge and high evaporation or transpiration
Limnocrene	Emergence of confined or unconfined aquifers in pool(s)
Mound	Emerges from a mineralized mound, frequently at magmatic or fault systems
Rheocrene	Flowing spring, emerges into one or more stream channels
Tinaja	(Usually) small pool in rock basin

Table 3. Characteristics of springs related to three kinds of aquifers (perched, local, regional) common in the desert southwest (created from Sada and Pohlmann 2006).

Characteristic	Perched	Local	Regional
Aquifer size	Very small	Small	Large
Water temperature	Cold	Cool	Warm
Solute concentration	Low	Low to moderate	Moderate to high
Total discharge	Very low	Low	Moderate to high
Discharge persistence	Ephemeral	Ephemeral to perennial	Invariant/perennial
Discharge site	Mountain	Piedmont	Valley bottom

and geology (e.g., bedrock lithology, permeability and porosity, location of contacts, fractures and faults, geomorphology, etc.) are the primary factors contributing to spring type and seasonality (Table 3). Springs in the arid Southwest fed by small, perched aquifers commonly (but not always) go dry seasonally or during drought (Sada and Pohlmann 2006). In contrast, springs in local aquifers that cover a larger area, such as an entire mountain range may also change seasonally and may go dry during extended droughts (Sada and Pohlmann 2006). Springs fed by regional aquifers, i.e., aquifers covering an enormous area, tend to be higher in solutes due to the depth and length of the groundwater flow path, and tend to have discharge rates that remain fairly constant through time (Sada and Pohlmann 2006).

We group the vital signs related to springs (Table 1) into four modules (water quantity, water quality, site condition, and site characterization) to aid in field data collection and analysis. We will monitor a suite of physical and biological characteristics to capture changes in surface water resources and biological communities.

1.1.1 Module 1 - Water Quantity

Water quantity and the timing and magnitude of flowing water determines the stability and persistence of a spring system, including the biological communities that it can support. Spring discharge and persistence are influenced by aquifer size, rate of groundwater recharge and geology (Sada 2013a; 2013b). In arid regions, recharge tends to be sporadic and confined to relatively small areas, but spring discharge can remain consistent until water tables decline below a threshold (Kreamer and Springer 2008). In springs with relatively low discharge, vegetation communities typically consist of upland and facultative wetland species adapted to drier conditions. In springs with generally high discharge, permanent stream channels, ponds or wetlands, riparian communities composed of obligate wetland species develop (Sada 2013a; 2013b).

1.1.2 Module 2 - Water Quality

Water quality is a critical measure of the chemical, physical and biological properties of an aquatic system. Aquatic ecosystems depend on particular water quality conditions. In this sense, "water quality" is relative for monitoring purposes. Deviations from of any particular water quality metric can trigger cascading changes in an ecosystem, even those occurring under harsh water quality conditions. The chemical "harshness" of a spring is due to high concentrations of salts and minerals as well as water temperature (Sada 2013a; 2013b). Higher water temperatures and total dissolved solids can be associated with long aquifer flow paths (Kreamer and Springer 2008). Waters that are saline or hard (high concentrations of calcium, magnesium and other metalloids or cations) can also create environments in which only fauna that are adapted to or tolerant of those conditions can live (Sada 2013a; 2013b).

Water quality monitoring in this protocol focuses on core parameters (temperature, specific conductance, pH, and dissolved oxygen) as defined by NPS Water Resources Division (NPS WRD 2002), turbidity (a useful water quality parameter per NPS WRD 2002), major ions (calcium, potassium, magnesium, chloride) and inorganics (sulphate, alkalinity).

This module focuses on how spring systems and hydrology may be changing rather than on nutrients (e.g., nitrogen, phosphorus) or biological condition. Nutrients and biological condition can provide insight into activities at a spring (Sada and Pohlman 2002) and were recommended parameters in the Sonoran Desert Network monitoring plan (Mau-Crimmins et al. 2005) and other inventory and monitoring protocols (e.g., Sada and Pohlman 2002; Sada and Pohlman 2006). However, data collected during the Sonoran Desert Network springs inventory revealed that nitrogen concentrations were generally less than 1 mg/L, phosphorus concentrations were less than 1 ug/L, and coliforms were generally less than 2500 CFUs (SODN unpublished data). Additionally, the cost and impact of nutrient and *Escherichia coli* (*E. coli*) analyses, both fiscally and through managing waste from analysis did not justify the collection of these of parameters.

1.1.3 Module 3 - Site Condition

Invasive non-native plants are a concern to managers in both networks (Mau-Crimmins et al. 2005; NPS CHDN 2010) and they are the only vital sign identified by the networks within the site condition module. Invasion of non-native plants can lead to a loss of native plants, altered hydrologic cycling and changed habitat available to animals (NPS CHDN 2010). Such invasions can compromise ecological functioning of spring ecosystems and can result in altered species diversity (O'Dell et al. 2005). Other disturbances can increase the susceptibility of spring ecosystems to infestations of invasive non-native plants (Weissinger et al. 2017; Fleishman et al. 2006), such as use by humans and livestock, scour and deposition events, and wildfire.

1.1.4 Module 4 - Site Characterization

There are no vital signs associated with the site characterization module as information from this module is intended to provide site-specific context for interpreting the other modules. Site characterization measures are generally qualitative assessments. Descriptions of geologic and hydrologic features and the vegetation community can provide context for the variables collected in Modules 1-3.

1.2 Key Communities

Arid-land springs are present in most parks in the Chihuahuan Desert and Sonoran Desert networks. The number of springs in each park varies, as does spring morphology, flow and water quality.

1.2.1 Springs in Chihuahuan Desert Parks

Surface water resources (e.g., arid-land springs and rivers) in Chihuahuan Desert Network parks (Table 4) are sparsely distributed across park lands, but critical to the persistence of native biota and many endemic species (NPS CHDN 2010).

In Amistad NRA, fewer than 10 springs and seeps have been located along the Devils and Pecos rivers

Table 4. Known number of springs, seeps, and tinajas in parks in the Chihuahuan Desert Network.

Park	Known Springs, Seeps and Tinajas
Amistad NRA	8
Big Bend NP	>100
Carlsbad Caverns NP	52
Guadalupe Mountains NP	32
White Sands NM	2 (1 adjacent)

(depending on the lake level as some may become inundated periodically) (NPS unpublished data; NPS CHDN 2010). Both rivers run through limestone bedrock through which springs also emerge (NPS CHDN 2010). The springs in Amistad NRA are located primarily on exposed cliff faces and do not support complex riparian communities.

Big Bend NP contains numerous seeps and springs along the Rio Grande as well as hundreds of springs and tinajas distributed throughout the park (NPS unpublished data). Together, these water sources provide habitat for numerous species living in the park and migrating through it. Spring discharge in the park may decrease due to drought and groundwater pumping. Springs within the Rio Grande Wild & Scenic River segment at Big Bend NP may be influenced by pumping in the Edwards-Trinity aquifer (NPS CHDN 2010).

More than 50 springs and a few tinajas have been documented in Carlsbad Caverns NP (NPS unpublished data). The park's most well-known spring is Rattlesnake Springs, which has provided water for park visitors and staff and nearby private land owners for more than 50 years. Fluctuations in annual precipitation and groundwater withdrawals affect flow from Rattlesnake Springs (NPS CHDN 2010).

Guadalupe Mountains NP contains more than 30 seeps and springs (NPS unpublished data). In addition to McKittrick Creek, the principal surface-water resources in the park include Smith Spring, Choza Spring, Manzanita Spring, Frijole Spring and Guadalupe Spring. Aquifers and the springs that flow from them in the region of Guadalupe Mountains NP are especially vulnerable to drought (NPS CHDN 2010).

At least three springs emerge within or adjacent to White Sands NM (NPS unpublished data). Surface waters, including those in springs, at White Sands NM are hypersaline. Contamination of surface and groundwater and depletion of groundwater may influence springs at White Sands NM (NPS CHDN 2010).

1.2.2 Springs in Sonoran Desert Parks

Seeps, springs or tinajas occur in all Sonoran Desert Network parks except Casa Grande Ruins NM and Tumacácori NHP (Table 5). Well-known water bodies include Quitobaquito Spring in Organ Pipe Cactus NM and Montezuma's Well in Montezuma Castle NM.

Table 5. Known number of springs, seeps, and tinajas in parks in the Sonoran Desert Network.

Park	Known Springs, Seeps and Tinajas
Chiricahua NM	15
Coronado NMem	13
Fort Bowie NHS	3
Gila Cliff NM	2
Montezuma Castle NM	2
Organ Pipe Cactus NM	165*
Saguaro NP	315*
Tonto NM	2
Tuzigoot NM	1

*Tinajas account for the majority of count

In addition to Quitobaquito Spring and pond, Organ Pipe Cactus NM contains several other (quasi) perennial springs, including Bull Pasture Spring, Williams Spring and Dripping Springs, and more than 60 tinajas (Sprouse et al. 2002). Williams and Quitobaquito springs are located near the U.S./Mexico border. Discharge and water quality have been monitored at Quitobaquito Spring and pond for many years, but border security restrictions limits access to Williams Spring. Dripping Springs is located in the Puerto Blanco Mountains. Bull Pasture Spring is in the Ajo Mountains. Tinajas are the most significant source of surface water within the monument. The majority of Organ Pipe Cactus NM's tinajas are in the Ajo Mountains (Sprouse et al. 2002) with tinajas also scattered throughout the Bates and Puerto Blanco mountains (Sprouse et al. 2002). Organ Pipe Cactus NM's springs and tinajas are intermittently subject to contamination by trash and other human impacts (Organ Pipe Cactus NM 2011).

Surface water at Chiricahua NM is relatively rare and tends to occur near Bonita and Rhyolite creeks, the park's two major drainages. Although tinajas do not occur at Chiricahua NM, twelve seeps and springs are known, including Shake Spring, Headquarters Spring, Silver Spur Spring, Superintendent's Spring and Bonita Spring. The King of Lead Mine, located adjacent to the monument directly upstream of Bonita Creek, poses a potential water quality concern at Chiricahua NM (Sprouse et al. 2002).

Thirteen seeps and springs are known at Coronado NMem, but tinajas do not occur (NPS unpublished data). Although the memorial is mostly upslope from many potential contaminants, past mining activities, groundwater withdrawal and contamination by human activities may impact the memorial's seeps and springs. For example, Blue Waterfall Seep occurs upstream of Mine #25 but the water is tinted blue after it flows through the mine tailings downstream of the spring orifice, suggesting impacts to water quality (Sprouse et al. 2002).

Three significant springs occur at Fort Bowie NHS: Apache Spring, Lower Mine Spring and Upper Mine Spring. Sonoran Desert Network crews identified two additional small springs during the spring inventory in 2010. Historically, Apache Spring provided a reliable source of water to American Indians, soldiers and wildlife, but discharge has decreased in recent decades (Filippone 2009). Soil loss within the Apache Spring watershed, drought and increased evapotranspiration have been identified as probable causes for the decreases in spring flow (Filippone 2009).

In Gila Cliff Dwellings NM, Cliff Dweller Canyon Spring runs along the trail to the Mogollon sites that are open to the public in Cliff Dweller Canyon. The intermittent springbook flows into the West Fork of the Gila River. The walls of Cliff Dweller Canyon also contain a number of seeps (Sprouse et al. 2002).

Two known springs are located at Montezuma Castle NM, including Expansion Spring that was identified in 2010 during an inventory of lands within the new expanded boundary. Located within a steep ephemeral drainage, this spring supports obligate riparian vegetation (NPS unpublished data). Montezuma Well, located in Well Unit north of the Castle Unit, is a large pool in a limestone sink formed the collapse of an underground cavern around a travertine spring (Sprouse et al. 2002). Although the area near Montezuma Well has seen an increase in population and water use, a decrease in the spring flow to Montezuma Well was not observed as of the late 1990s (Konieczki and Leake 1997).

Over a dozen springs and seeps and more than 250 tinajas are known to occur in the Rincon Mountain District of Saguaro NP (NPS unpublished data). Wildfires have had a significant effect on tinajas in the Rincon Mountain District and the wildlife they support (Parker 2006). Following fires, tinajas can fill with sediment and ash. The increase in turbidity in tinajas or their complete infilling by sediment can influence wildlife and eliminate wildlife habitat (Sprouse et al. 2002). The Tucson Mountain District contains one known surface spring, the ephemeral King Canyon seep, and numerous seeps deep inside historic mines (Sprouse et al. 2002), which will not be monitored under this protocol due to safety and access concerns.

At Tonto NM, springs provided water sources for the ancient inhabitants of the cliff dwellings and support unique vegetation communities in the monument today. Cave Canyon Spring was likely a water source for the Upper Cliff dwelling. It emerges in Cave Creek below the cliff and supports a small riparian area (Sprouse et al. 2002). A spring at the confluence of Cave and Cholla canyons likely was a water source for the Lower Cliff Dwelling (Sprouse et al. 2002). However, this spring has not flowed since the early 1960s, likely due to drought and the installation of a domestic water well (Martin 2001). The quasi-perennial Hidden Spring supports a mesquite bosque on Hidden Ridge.

Historically, Shea Spring, the only spring known at Tuzigoot NM, was the sole source of water in Tavasci Marsh. Today, Tavasci Marsh is also fed by Pecks Lake, an artificial reservoir located adjacent to the park (Schmidt et al. 2005), although Shea Spring is still an important water source for the marsh (Sprouse et al. 2004).

1.3 Key Stressors and Disturbances

Common stressors to springs biota include reduced water availability such as drying, water temperature extremes (freezing, high temperatures), reduced light penetration (due to turbidity) and biochemical conditions outside the usual environmental envelope for a given site (Sada 2013a; 2013b). Humans have exploited the resources found at springs since prehistoric times, and have modified springs, altering where, how and how much water is present in them (Sada 2013a; Sada 2013b), thus additionally impacting those systems. Groundwater extraction is also associated with reduction or loss of spring flow worldwide (Unmack and Minckley 2008) and, for example, has reduced spring flow in Nevada (Dudley and Larson 1976) and has caused springs to go dry in southern California (Miller 1961).

Climate change is an emerging impact on springs in the American Southwest, with expected increased air temperatures, reduced precipitation, increased evaporation rates, increased drought frequency, and increased frequency and magnitude of extreme weather events (Garfin et al. 2013). These changes may cause springs to go dry (Comer et al. 2012; Dekker and Hughson 2014) or experience reduced flow (Grimm et al. 1997, Weissinger et al. 2016) which may result in disruption of ecological functions and loss of species diversity (Garfin et al. 2013). For example, springs in the Sonoran Desert have been rated as moderately vulnerable to climate change with their high sensitivity to projected changes in climate and climate stress offset by high ecological resiliency (Comer et al. 2012). Examples of potential impacts include:

- Loss of aquatic and riparian habitat and surface water as spring flows decline (Grimm et al. 1997; Comer et al. 2012; Weissinger et al. 2016), as springs dry up completely (Comer et al. 2012; Dekker and Hughson 2014), or become more ephemeral (Dekker and Hughson 2014);
- Harsher chemical environments (including increased salinity) at springs due to increased evaporation and lower flow rates due to warmer temperatures (Comer et al. 2012);
- Invasion of non-native plants and animals, hybridization of non-native with native species (e.g., Rahel and Olden 2008) or shift in dominance to more tolerant species (e.g., replacement of riparian plant species with upland species; Patten et al. 2008) due to changes in temperature and precipitation that alter species competitive ability and changes in groundwater levels; and
- Decreased habitat quality due to increased erosion from more frequent fires and floods (Comer et al. 2012).

Disturbances are discrete events that remove biomass or otherwise disrupt biotic communities by modifying resources or changing the abiotic environment (Pickett and White 1985). Natural disturbance regimes that can affect spring ecosystems include drought, flood and fire (Sada 2013a; 2013b). Flooding and fires lead to events that can fill and/or scour springs and tinajas and alter flow paths of surface and groundwater, leading to fundamental changes in the location of spring orifices (emergence points) and flow rates (Parker 2006).

Human stressors and disturbances can directly alter spring systems. Damming and water diversion can alter habitat availability for aquatic organisms, both positively and negatively (Shepard 1993). Livestock can trample and remove vegetation (Minckley and Unmack 2000), increase nutrient inputs (Shepard 1993; Minckley and Unmack 2000), and alter the banks of springbrooks (Shepard 1993). Human trampling can also alter springbanks (Sada 2001). Changes in nearby land use and on-site recreational use can stress springs (Comer et al. 2012). Recreational swimming and camping can result in changes to habitat availability and increased inputs of trash and fecal material (Shepard 1993).

Broadly speaking, spring ecosystems have co-evolved with natural disturbances, although human disruptions of natural disturbance regimes can pose specific threats to spring persistence, water quality and ecological function (Sada 2013a; Sada 2013b). Organisms have a variety of evolutionary responses to disturbance. Enright et al. (2014) define resistance as “the capacity of extant populations to survive disturbance through persistence,” and resilience as “their capacity to recover to pre-disturbance abundance levels through recruitment.” These paired concepts provide a useful framework for predicting biotic responses to disturbance, and increasingly are used to investigate interactions between disturbance regimes and the most extensive human perturbation: human-caused climate change (Grime et al 2000; Diaz-Delgado et al. 2002).

This protocol seeks to characterize the impact of natural and human disturbance (Sada and Pohlmann 2006), and observe changes in magnitude of the disturbance over time.

2. Monitoring Goals and Objectives

One of the main goals of the NPS I&M Program is to provide park managers with information that allows them to make well-informed management decisions and to work more effectively with other agencies. The overarching goal of the arid-land springs monitoring program is to detect broad-scale changes in aquatic and riparian ecological condition by observing selected drivers, stressors, and processes. In order to meet this goal, we will monitor a suite of vital signs and measures organized into four modules: water quantity (including persistence), water quality, site condition, and site characterization (Table 6). We will sample all four modules at each spring during every visit unless insufficient water is present. The monitoring objectives, vital signs, parameters and measurement frequency for each module are summarized in Table 6. Although riparian vegetation is not a module in this version, the presence of a select list of obligate and facultative wetland species, genera and families is included in the site condition module to provide context for the persistence of springs. There are no monitoring objectives for the site characterization module as this information is intended to provide on-site contextual information to assist in the interpretation of data collected for the other three modules.

Additional vital signs or parameters considered but not incorporated in this protocol at this time include nutrient dynamics, microorganisms, riparian vegetation, aquatic macroinvertebrates, and tinaja bathymetry (as part of surface water dynamics vital sign). As described in Section 1.1.2, nutrient concentrations and *E. coli* (microorganisms) were observed at relatively low levels during the Sonoran Desert Network inventory. These parameters were not included in this version of the protocol after comparing the likelihood of meaningful data verses the cost of conducting the tests, and the costs of disposing of hazardous waste produced from these tests. Aquatic macroinvertebrates were collected during inventory efforts for both networks and as part of the Chihuahuan Desert Network pilot monitoring effort. In addition to costly data analysis, the authors concluded that it was not possible to collect a repeatable, quantitative sample at most springs. Macroinvertebrates will be considered in future versions of the protocol as techniques/technologies, such as environmental DNA, evolve. Several pilot efforts at Sonoran Desert Network were undertaken for riparian vegetation (e.g., Devantier 2014). However, the networks were not able to develop a repeatable method of data collection that was sustainable considering the available resources to collect data. Additionally, staff botanists thought that the level of expertise required to identify the somewhat rare species found at many springs too specialized for standard field work, and instead recommended that a indicator species/genera/families be monitored instead. Tinaja bathymetry methods have been developed for Saguaro NP (O'Brien et al. 2015) and will likely be included in future versions of this protocol. As indicated above, these vital signs and parameters will continue to be evaluated for inclusion in future versions of the protocol, depending on available resources and need.

Table 6. Monitoring objectives and associated parameters for each springs monitoring module and associated vital signs.

Module	Vital Signs	Monitoring Objective	Measured Parameters	Measurement Frequency
1 – Water Quantity	Persistence of springs	Determine status and long-term trend in the persistence of surface water (number of dry days)	Number of wet and dry days	Every 1 or 2 hours
	Surface water dynamics	Determine status of spring discharge and wetted extent	Spring discharge, wetted extent (length, width, depth)	Annual, in spring
2 – Water Quality	Water quality (core parameters)	Determine status in core water quality parameters (temperature, pH, conductivity and dissolved oxygen)	Temperature, pH, specific conductance, dissolved oxygen	Annual, in spring
	Water chemistry, major Ions	Determine status in select major ions and alkalinity	Potassium, magnesium, calcium, sulfate, alkalinity, chloride	Annual, in spring
3 – Site Condition	Invasive non-native plants	Determine presence (status) of select obligate/facultative wetland plants and invasive non-native plants	Presence of species, genera, and families	Annual, in spring
	None	Determine status of anthropogenic and natural disturbances	Categorical rating of disturbance categories	Annual, in spring
4 – Site Characterization	None	None	Contextual information (e.g. spring type, orifice locations, diagrams, descriptions)	Every 5 years

3. Sampling Design

Spring ecosystems will be monitored in five Chihuahuan Desert Network parks (Amistad NRA, Big Bend NP, Carlsbad Caverns NP, Guadalupe Mountains NP and White Sands NM), and nine Sonoran Desert Network parks (Chiricahua NM, Coronado NMem, Fort Bowie NHS, Gila Cliff Dwellings NM, Montezuma Castle NM, Organ Pipe NM, Saguaro NP, Tonto NM and Tuzigoot NM). Monitoring will occur at one or more "sentinel springs" in each park. The use of sentinel sites is similar to targeted or judgmental designs (sites chosen based on representativeness or other criteria) in that information from sentinel sites can only be applied to a given sentinel site and inference to the entire spring population is not possible. However, given the uniqueness of springs within the network parks, the definition of a target population was not possible (Predick 2016), precluding the use of other sample designs (e.g., Generalized Random Tesselation Stratified (GRTS) at Big Bend NP). Although Chihuahuan Desert Network utilized a GRTS approach during pilot monitoring efforts (2014-2016), the network decided to focus on sentinel springs to better incorporate park priorities and due to the difficulty in defining a target population. Depending on each network's budget and field effort, additional sentinel springs may be monitored in the future. Any substantial change to the sampling design will be detailed in a new version of this protocol.

3.1 Spatial Sampling Design

3.1.1 Sentinel Site Prioritization

Variation in local geology and hydrology makes specifying meaningful target populations for springs difficult, even on local scales (Predick 2016; Weissinger et al. 2017). Instead we focus our monitoring effort on "sentinel springs" selected using a decision tree (Figure 4). The Northern Colorado Plateau Network also monitors a suite of sentinel springs (Weissinger et al. 2017).

Sentinel sites were selected using a decision tree (Figure 4; Appendix 1) with sites prioritized for monitoring. This decision tree was informed by four other efforts for prioritizing springs for monitoring or conservation. We incorporated management priority, access and stable sampling locations in a fashion similar to that used by the Northern Colorado Plateau Network to select sentinel sites (Weissinger et al. 2017). We included Sada's (2013a; 2013b) presence of wetland species, aquatic habitat (surface water) persistence, scouring (repeatable measurement location), and human disturbance factors used to prioritize springs to monitor for climate change impacts. Surface water presence and persistence, wetland species, and disturbance criteria were adapted from a dichotomous key developed for ranking the conservation importance of montane springs at the White Sands Missile Range (Thompson et al. 2002).

In general, springs were not chosen by either network as sentinel sites if they:

1. Are inaccessible according to network safety protocols and/or take too long to access (> 3 hour hike).
2. Are too small for any type of survey (e.g., they have no observable or measurable flow, no perennial riparian vegetation or if they consist of little more than "wet spots" on the ground or cliff face).
3. Have extensive modification or diversion.
4. Are intermittent streams (i.e., channel is runoff-dominated and subject to scour).
5. Show signs of frequent scouring (i.e., erosion).
6. Are a site that a park requests to be excluded from sampling.

3.1.2 Chihuahuan Desert Network Sentinel Site Selection

The Chihuahuan Desert Network scored known springs using a 1-8 scale determined by the decision tree (Figure 4; Appendix 1) to prioritize sentinel spring sites for monitoring (with 1 being the highest priority). A total of 38 springs were selected for monitoring (Table 7). Data for scoring came from the network's inventory (2010-2012) and pilot monitoring (2014-2017) efforts (NPS unpublished data). Potential sites were then validated by the network's field crew lead and ecologist/physical scientist. For scoring springs according to Figure 4, we determined "yes" or "no" accordingly:

- Accessibility – A spring received a "yes" if:
    - Safe access was possible (based on access descriptions), AND
    - Hiking time was less than three hours from a frontcountry or backcountry starting location (based on access descriptions).
    - Theft potential (based on communications from park staff) was considered during validation by field crew lead.

- Presence of surface water – A spring received a "yes" if surface water was present during any visit to a site by network staff (during inventory or monitoring).
- Repeatable measurement locations – A spring received a "yes" if:
  - Discharge measurements were collected on at least half of network visits to a spring, OR
  - Water quality measurements were collected on at least half of the network visits, AND
  - Spring is not located in a wash (based on scouring ratings, descriptions recorded during network visits, photographs, and a GIS overlay of spring locations with a 10m buffer of drainages in the National Hydrography Dataset High Resolution (USGS 2007-2014).
- Importance to park – A spring received a "yes" when the park staff indicated that it was important. Springs deemed important to park received a final score of 1-4, otherwise scores were 5-8.
- Perennial water – A spring received a "no" and a final score of 3 or 4, or 7 or 8 if none of the below conditions were met. A spring received a "yes" and a final score of 1 or 2, or 5 or 6 if:
  - Surface water was likely present on more than half of the days monitored according to temperature sensors (after Anderson et al. 2015), OR
  - Facultative/wetland vegetation was recorded as present during any network visit (after Sada 2013a; 2013b), OR
  - Sensitive macroinvertebrates were present during any network visit (after Sada 2013a; 2013b).
- Human alteration/disturbance – A spring received a "no" if the spring was in the bottom half of standardized ratings of anthropogenic disturbance ratings for network springs. Sites with the final priority ranking of 1, 3, 5, or 7 had relatively few anthropogenic disturbances, and those that were disturbed were ranked 2, 4, 6, or 8.

3.1.3 Sonoran Desert Network Sentinel Site Selection

The Sonoran Desert Network focused on known springs identified by park managers in the Sonoran Desert Network monitoring plan (Table 8) (Mau-Crimmins et al. 2005). The Sonoran Desert Network utilized the decision tree (Figure 4) and similar data from spring inventory and pilot monitoring efforts to guide selection of 37 sentinel springs, but used a less formalized process than the Chihuahuan Desert Network did.

Table 7. Number of sentinel springs per park monitored by the Chihuahuan Desert Network.

Park	Sentinel Springs
Amistad NRA	4
Big Bend NP	19
Carlsbad Caverns NP	7
Guadalupe Mountains NP	5
White Sands NM	3

Table 8. Number of sentinel springs per park monitored by the Sonoran Desert Network.

Park	Sentinel Springs
Chiricahua NM	5
Coronado NMem	5
Fort Bowie NHS	2
Gila Cliff NM	2
Montezuma Castle NM	1
Organ Pipe Cactus NM	4
Saguaro NP	16
Tonto NM	1
Tuzigoot NM	1

3.2 Temporal Sampling Design

Due to programmatic constraints (time and money), each sentinel spring is sampled once during the vernal season (February – May for Chihuahuan Desert Network, March – July for Sonoran Desert Network) each year. Sampling during the vernal season allows data collection when precipitation inputs are relatively low and crew safety issues are minimized (i.e., less heat exposure, fewer extreme weather events). The relatively dry vernal season provides similar climate conditions between years. Although more frequent sampling would be preferred for most parameters, our sampling frequency and timing are a compromise between pragmatic constraints (time and money) and the variability of the biogeochemical, geomorphological and hydrological phenomena of interest. If the cost of data collection and processing can be reduced, we may modify sampling frequency to allow for detection of trends in more parameters. Although sampling once per year only allows for a description of the status for most parameters (persistence of springs is the notable exception),

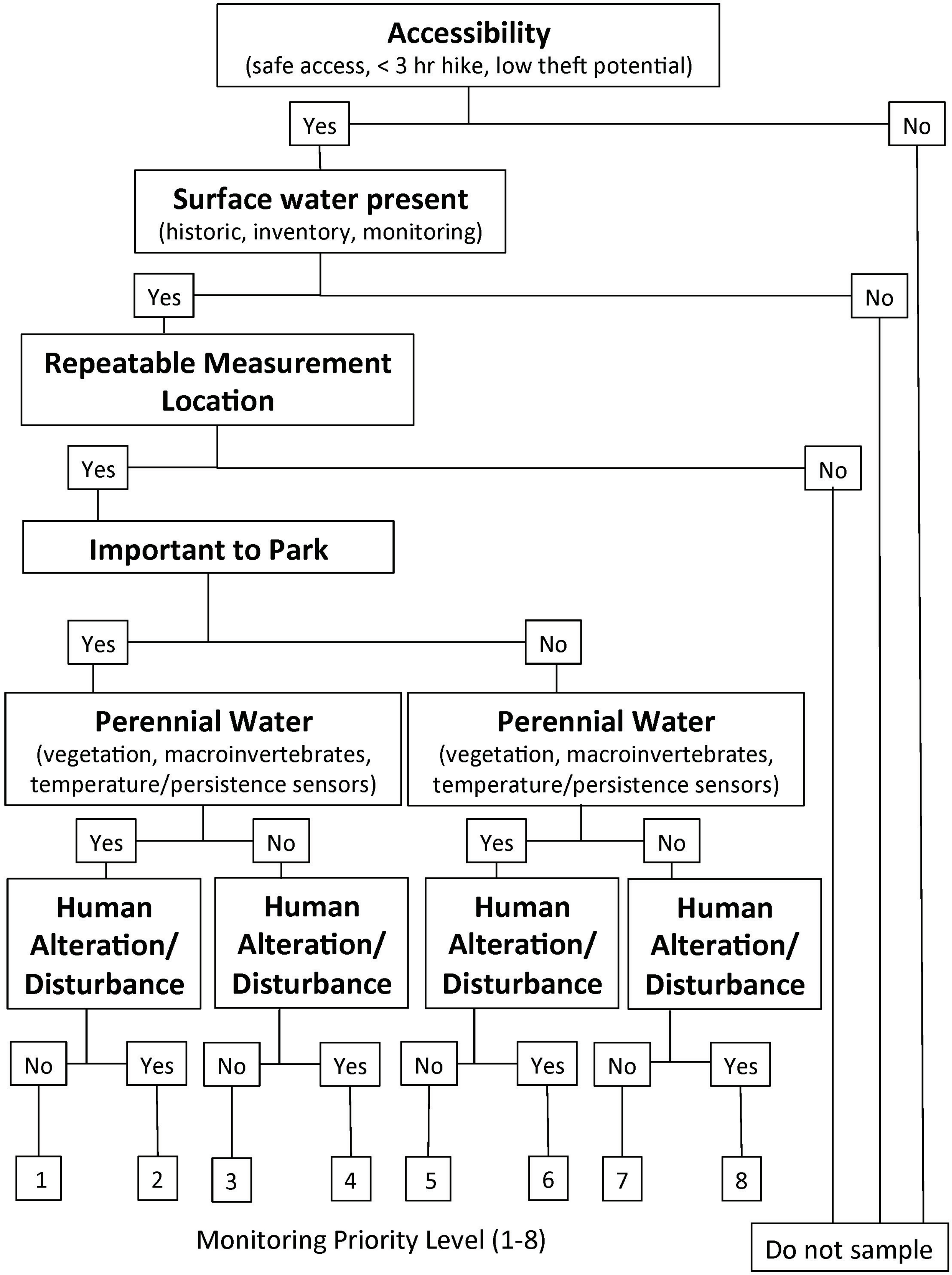

Figure 4. Decision-tree for sentinel spring selection based on Thompson et al. 2002; Sada 2013a; Sada 2013b; and Weissinger et al. 2017.

the information collected will be useful to identify potential issues related to spring water quality, and it may provide insight when considered with other observations at the spring to address management concerns. In addition, we will sample each spring on as close to the same day as possible to potentially facilitate long-term trend detection. After five years of data collection, we will evaluate the data for their potential ability to detect trend and for potential reassignment among modules (e.g., shift some parameters to the site characterization module, which is collected every five years).

4. Field Methods

This protocol describes four modules (water quantity, water quality, site condition, and site characterization), with a core set of minimum parameters to monitor the status and long-term trends of spring, seep and tinaja ecosystems (Table 9). A two-person crew should be able to collect these data in 4-5 hours. The following sections describe each module and its associated components. Although vital signs identified during initial network planning differed somewhat between the networks (Table 1), the modules and field data collection are implemented identically across the networks (Table 9). Additional parameters, such as macroinvertebrates and riparian vegetation, may be added in future versions of the protocol.

Spring monitoring in the Sonoran and Chihuahuan Desert networks has similar modules and parameters to those in protocols used by other I&M networks (e.g., Northern Colorado Plateau Network, Mojave Desert Network, Southern Colorado Plateau Network). This protocol was based on inventory methods developed by Sada and Pohlmann (2006) for springs in the Mojave Desert Network. These methods were also used for inventories of springs in the Sonoran and Chihuahuan Desert networks. In addition, the Springs Stewardship Institute developed methods for inventory of spring ecosystems (Stevens et al. 2016) and this protocol shares parameters with that effort. An earlier version of the Springs Stewardship Institute protocol was applied to springs in the Upper Santa Cruz River basin (Arizona) by the Sky Island Alliance to assess spring systems within the region, including Saguaro NP (Misztal et al. 2016).

4.1 Module 1 - Water Quantity

The water quantity module consists of data collection to provide information on the persistence of springs, water quantity and wetted extent. These measurements relate to the surface water dynamics and persistence of springs vital signs. Detailed field methods are described in SOP 7.

4.1.1 Persistence of Springs

In most cases, the persistence of surface water springs is estimated by analyzing the variance of temperature measurements taken every 1-2 hours by electronic data recorders (Anderson et al. 2015). Paired sensors are deployed in each spring near the primary orifice (point of groundwater emergence) and in a nearby tree or shrub. The daily variance in temperature for the sensor placed at the orifice(Anderson et al. 2015), and potentially differences between sensors, are utilized to estimate presence of water, as submersion of the orifice sensor reliably mediates diurnal temperatures relative to air temperature (Anderson et al. 2015). Temperature sensors and data are retrieved and new sensors are deployed annually.

In rare instances, relatively high visitation, presence of water well pumps, frequent flow events, or other local factors (such as the prevalence of freezing temperatures) may limit the practical deployment of temperature sensors. At these locations, we may install pressure transducers in subsurface piezometers (shallow wells) or in nearby domestic water wells to detect the presence and estimate the quantity of surface and subsurface water. Pressure transducers measure the pressure of water above the instrument, yielding a continuous measurement of water level within a well, and are commonly used in groundwater monitoring and other hydrologic applications (Filippone et al. 2014). See Cunningham and Schalk (2011) for additional details on pressure transducers and their applications.

4.1.2 Spring Discharge

Flow (i.e., discharge) is measured at an appropriate and stable location within the site. The volumetric procedure, e.g., measuring the volume of water collected over a pre-specified time, is used at most springs. A minimum of five measurements per visit is collected and are averaged to determine flow (liters per minute). At pools or tinajas without outflow, stage (i.e., water elevation) is measured to estimate water quantity.

4.1.3 Wetted Extent

Wetted extent includes surface water and wet spots where water pools when pressed. At sites with standing water, three or five sets of length, width, and depth measurements are taken. The number of measurements depends on size of the standing water. At springs with brooks (spring-fed streams), the length of the main brook is measured (up to 100m) and width measurements are made at 10, 15, or 20 cross sections (depending on brook length). At five cross sections, water depth, detritus depth and substrate are recorded. If there are multiple orifices with springbrooks, the main brook is measured as

Table 9. Monitoring method section, parameters, measurement frequency, objectives, and related stressors for each springs monitoring module and associated vital sign(s).

Module	Vital Signs	Field Method Section	Parameter(s)	Measurement Frequency	Monitoring Objective or Purpose	Related Stressor(s)
1 – Water Quantity	Persistence of springs	Persistence of springs	Number of wet and dry days	Every 1 or 2 hours	Determine status and long-term trend in the persistence of surface water (number of dry days)	Loss of aquatic and riparian habitat
	Surface water dynamics	Spring discharge	Discharge (L/min)	Annually	Determine status of spring discharge and wetted extent	Loss of aquatic and riparian habitat
	Surface water dynamics	Wetted extent	Length, median wetted width and depth, median particle size, median detritus depth	Annually	Determine status of spring discharge and wetted extent	Loss of aquatic and riparian habitat (total area and substrate)
2 – Water Quality	Water quality (core parameters)	Core water quality parameters	Temperature, pH, specific conductance, dissolved oxygen	Annually	Determine status in core water quality parameters (temperature, pH, conductivity and dissolved oxygen)	Harsher chemical environments
	Water chemistry, major ions	Water chemistry	Potassium, magnesium, calcium, sulfate, alkalinity, chloride	Annually	Determine status in select metal and metalloids, inorganics and alkalinity	Harsher chemical environments
3 – Site Condition	None	Disturbance	Categorical rating of disturbance categories	Annually	Determine of anthropogenic and natural disturbances	Decreased habitat quality
	None	Photo points	Landscape photo points, feature photos	Annually	No objective. Contextual information for interpretation and repeat sampling relocation.	Loss of aquatic and riparian habitat, decreased habitat quality
	None	Obligate/facultative wetland plants	Presence of species, genera, and families	Annually	Determine presence (status) of select obligate/facultative wetland plants	Loss of aquatic and riparian habitat
	Invasive non-native plants	Invasive non-native plants and wildlife	Presence of species	Annually	Determine presence (status) of select invasive non-native plants	Invasive non-native plant and animal invasion
4 – Site Characterization	None	Spring type and characterization	Spring type, number and type of channels, slope, aspect	Every 5 years	No objective. Contextual information for interpretation.	Loss of aquatic and riparian habitat
	None	GPS locations	Locations of orifices, sampling locations, landscape photo points	Every 5 years	No objective. Contextual information for interpretation and repeat sampling relocation.	Loss of aquatic and riparian habitat
	None	Site diagram and description	None	Every 5 years	No objective. Contextual information for interpretation and repeat sampling relocation.	Loss of aquatic and riparian habitat
	None	Vegetation community description	None	Every 5 years	No objective. Contextual information for interpretation.	Loss of aquatic and riparian habitat

described previously and secondary brooks are measured for length only.

4.2 Module 2 - Water Quality

The water quality module includes core water quality parameters and water chemistry and relates to the water quality vital signs. Detailed field methods are described in SOP 6.

4.2.1 Core Water Quality Parameters

The core water quality parameters of water temperature, specific conductance, pH and dissolved oxygen reflect the function of the physical and biological environment with which water interacts. Monitoring these parameters is consistent with the NPS service-wide Water Quality Monitoring Program, which requires each network to collect these data as part of any water quality monitoring effort and recommends turbidity as a useful parameter (NPS WRD 2002).

Core water quality parameter measurements are taken using a multiparameter meter and, when available, a standalone optical dissolved oxygen instrument. The multiparameter meter measures specific conductance, water temperature, dissolved oxygen, and pH. Many meters also calculate total dissolved solids from conductivity (Roman et al. 2003). The optical dissolved oxygen instrument only measures dissolved oxygen. The instruments are calibrated frequently, at least at the beginning of each day and post-calibrated (checked) at the end of the day (instructions are located in the task instruction (TI) and summarized in SOP 6). Turbidity is collected by the Sonoran Desert Network whereas Chihuahuan Desert Network only records total dissolved solids. Collection of turbidity data is at the discretion of each network's protocol lead. Measurements of water quality parameters are collected at each sampling event, except when water flow is too low to have sufficient depth for submersion of the relevant instrument probes. Water quality measurements are taken as close to the orifice as possible.

4.2.2 Water Chemistry

Water chemistry (major ions) measurements (alkalinity, metals/metalloids and inorganics) are collected as grab samples during the site visit, just prior to core water quality parameter measurements. Generally, samples are analyzed in the field by network staff (using a spectrophotometer) but in some circumstances (such as in the case of high salinity and for springs at White Sands NM) analysis takes place at a contracted lab certified according to state, federal, Environmental Protection Agency, U.S. Geological Survey and NPS Water Resources Division standards. Additional parameters (e.g., nitrogen and phosphorus) may be analyzed at the protocol lead's discretion.

4.3 Module 3 - Site Condition

The site condition module is based on inventory methods developed for the Mojave Desert Network (Sada and Pohlman 2006) and utilized by the Chihuahuan and Sonoran Desert networks to inventory springs in 2010-2012. Detailed field methods for the site condition module are described in SOP 4 (photo documentation) and SOP 5 (remainder of site condition module). The site condition module relates to the invasive non-native plant vital signs and provides additional information on the condition of springs. The module consists of four subsections: disturbance, photo points, obligate/facultative wetland plants and invasive plants and wildlife.

4.3.1 Disturbance

The disturbance assessment is a categorical measure of natural and anthropogenic disturbance and the level of stress on vegetation and soils in spring ecosystems (Sada and Pohlmann 2006). Types of natural disturbance evaluated include flooding, drying, fire, wildlife, windthrow of trees and shrubs, beaver activity and insect infestations. Types of anthropogenic disturbance include roads and off-highway vehicle trails, hiking trails, livestock, feral animals, removal of invasive non-native plants, flow modification, and contemporary human use as evidenced by presence of campsites, fire rings, trash, etc. An "other" category is also included for both natural and anthropogenic disturbances. Magnitude of each disturbance on the spring is classified on a scale of 1 - 4, where 1 = undisturbed, 2 = slightly disturbed, 3 = moderately disturbed, and 4 = highly disturbed (Sada and Pohlmann 2006).

4.3.2 Photo Points

Photographs are taken from designated photo points to show the spring and its landscape context. Photos are also taken of the spring orifice(s), sampling locations, and any other distinguishing or unique features to aid in relocation of the site and interpretation of change in the other measures.

Additional photographs may be taken to replicate historic photographs, if applicable.

4.3.3 Obligate/Facultative Wetland Plants
The presence of a suite of obligate or facultative wetland plants is noted during each visit using a checklist. The plants in the checklist consist of forbs/herbs, grasses, trees/shrubs and sedges/rushes that indicate persistent water and is modified from Sada's (2013a; 2013b) list of wetland indicator plants. The checklist is complemented by a description of vegetation that is completed in the site characterization module.

4.3.4 Invasive Non-Native Plants and Wildlife
The presence and density (using four density categories: 1–5 plants, scattered patches, evenly distributed patches, and matrix; Folts-Zettner et al. 2016) of invasive non-native plants, by species, is recorded during each visit. The presence of invasive non-native aquatic wildlife species such as American bullfrog (*Rana catesbiana*) or crayfish (*Orconectes* spp.) is also recorded.

4.4 Module 4 - Site Characterization
The site characterization module is a modification of the inventory methods developed for the Mojave Desert Network (Sada and Pohlmann 2006) and was utilized by the Chihuahuan and Sonoran Desert networks to inventory springs in 2010-2012. Detailed field methods are described in SOP 3.

The components of the site characterization module are completed once every five years. The monitoring crew reviews the most recent complete characterization during each annual visit and notes major changes as needed (such as a more efficient access route). Additionally, if a significant event (e.g., fire, flood) occurs within the five-year interval or if trends of potential concern are noted, then early recollection of data for the full site characterization module may take place.

The site characterization module includes four subsections: spring type and characterization, GPS locations, site diagram and site description, and vegetation community description. This module provides context for interpreting change in the other modules.

4.4.1 Spring Type and Characterization
The spring type (Table 2), slope, aspect and general characterization of the springbrook (if present) are recorded every five years.

4.4.2 GPS Locations
The GPS locations of the orifice(s), sampling locations (where water quality, water quantity and photo points are collected), landscape photo points and other features of interest are collected. GPS locations of orifices combined with photographs and written descriptions will be used to determine whether spring source locations have changed significantly (> 3m), or whether the number of sources within a spring complex has changed.

4.4.3 Site Diagram and Description
Site diagrams and descriptions are useful to describe the overall context of the spring ecosystem. Site diagrams and descriptions are generated every five years. If site diagrams and descriptions exist from previous efforts, they will be reviewed and updated as necessary to reflect current conditions.

4.4.4 Vegetation Community Description
A systematic description of the vegetation is written every five years. The description focuses on the vegetation community surrounding the spring that is clearly influenced by the presence of water and describes how the topography and geomorphology influences the vegetation community, as well as how similar the vegetation community at the spring is to the surrounding area. While obligate/wetland plants are recorded annually as part of the site condition module, this description is broader and qualitative to provide context for site interpretation.

5. Data Management

Effective data management ensures data quality, security, longevity and availability, and is critical to the success of the springs monitoring program. Data management for this protocol is a cyclic effort that begins in January prior to field training and ends in July with the season close-out. This chapter presents an overview of the monitoring database and general procedures for organizing, entering, verifying, validating, certifying, documenting, distributing and archiving the data collected under this protocol. Additional information and context for this chapter may be found in the Chihuahuan Desert Network and Sonoran Desert Network data management plans (Richie 2009 and Angell 2005, respectively). Additional details and instructions for tasks in each stage of the data management cycle are contained in SOP 9. The standards, policies, and procedures used by Chihuahuan Desert Network and Sonoran Desert Network are detailed in a Data Quality Standards document for this protocol (McIntyre et al. 2018).

5.1 Data Organization

This long-term monitoring project will generate large quantities of spatial and tabular data, images, and numerous products. A well-organized digital file structure is critical to avoid confusion and potential data corruption. The two networks maintain unique file organization structures. Although data from both networks are managed in the same geodatabase and relational database, each network is responsible for management of other products, such as images, data sheets, reports, and archive materials. At Chihuahuan Desert Network, each protocol has a similar folder structure on network drives, in which protocol-related information is kept. At Sonoran Desert Network, each project uses a similar folder structure replicated on both active and archive network drives. Data for the current (ongoing) field season are stored on the active drive. At the end of each field season, completed products and other seasonal files are transferred to the permanent project folder on the archive drive, where they are stored in read-only format.

5.2 Data Model

A normalized relational database is used to store and manage springs protocol data. In addition, this protocol also leverages other databases common to workflow throughout the office, such as personnel and species taxonomy. These databases are integrated into applications in a way that allows improvements and revisions to the application without altering the actual data structure or any of the records in the back-end database data tables.

The springs database has indicators to represent where data is in the data life cycle. The database also has an automated log file that tracks the users who access it, as well as any modifications they may make to either the database structure or data. The networks maintain metadata and documentation that articulates the data dictionary, management of the database, and versioning procedures.

The user applications contain forms for data entry and modification, queries for verification, validation and data export, and code for creating custom features designed to maintain efficient workflow. The applications will have documentation that describes the procedures for management and versioning, as well as easy-to-understand user instructions.

The springs database is based on the I&M Division Database Standards (Frakes et al. 2015). The design includes standardized core tables for elements (such as Locations and Events) that are common to most monitoring datasets, as well as a field data table that can be duplicated and customized to meet individual project data requirements. The standard also outlines a variety of other best practices ranging from data integrity requirements such as field constraints to organizational concerns such as naming conventions.

The network protocol leads should have a thorough understanding of the database structure and procedures for using the application. All documentation requested by the protocol lead, staff or partners will be made available in read-only format.

5.3 Data-Entry Procedures

Sampling data for springs is preferentially recorded electronically on ruggedized field laptop computers, tablets or GPS units or on paper field data sheets when necessary. Electronic data collection minimizes transcription errors and increases efficiency. Data collected on field computers and other digital recording devices are subject to a series of backup procedures in the field and office (SOP 9) to ensure adequate data redundancy. In the event of equipment failure in the field, paper data sheets are completed to avoid lost information.

Data QA/QC procedures are built into electronic field recorders and the database to eliminate as many potential data-entry errors as possible. For example, pick lists are used to limit values entered into a field to ensure that only valid names or measures are entered. Numeric criteria are also used to ensure that values entered fall within an acceptable range (for example, pH values may not exceed 14).

Data recorded on paper data sheets are entered into the database as soon as possible because doing so facilitates finding and correcting errors by field staff. Entering data after the field season ends is not preferable.

Entered data are held in a set of temporary databases until certification procedures have been competed, and then data are uploaded to the master database. This allows less restricted access to the current season's data while it is being actively collected and processed, while ensuring certified data from previous seasons are not editable.

5.4 Data-Certification Procedures

Data verification is the process of checking the accuracy of digital data against copies of original paper data sheets. This critical but time-consuming step is partially eliminated through the use of field computers for direct data entry. However, data recorded on and entered from paper data sheets still need to be verified.

Data validation is the process of reviewing digital data for range and logic errors. Although some validation features, are built into the database itself via data-entry forms (see above), range limits and queries, the project leader or another person familiar with the data must further review the dataset for these types of errors. For data that were directly input in the field, a paper version of each completed data form should be exported for archival purposes after data validation has been completed. Spatial data are validated according to the procedures specified in SOP 9 using the latest version of ArcGIS software (ESRI, Inc.).

Data certification is the process of ensuring that the dataset (i.e., the database containing all of the records for that year) has been verified and validated for accuracy, is complete and is fully documented. Data certification is completed annually for all tabular and spatial data and photographs. This process is documented by the project leader in order to notify the data manager that data are ready for archiving and storage. After the dataset is certified, it can be used in analysis and reporting.

5.5 Metadata Procedures

All data produced by the springs monitoring protocol should have accompanying metadata, especially if any data are going to be distributed. Metadata help to preserve data history, allow the data life cycle to be effectively managed, identify the effective and administrative limits of data use and instill data accountability by requiring producers to state what they do and do not know about the dataset.

At the most basic level, metadata ensure the longevity and usability of the dataset. When changes in personnel cause an organization to lose institutional knowledge, undocumented data can lose their value. Subsequent employees may be left with minimal understanding of the contents and uses of a digital database and may be unable to trust the results generated from those data. Also, lack of knowledge about data produced by other organizations can lead to duplication of effort. For these reasons, in the long term, metadata are well worth the investment of time and resources required to generate them (FGDC 2018).

For geographic metadata, refer to the Sonoran Desert Network Metadata Development Guidelines stored locally at Sonoran Desert Network. All database objects (e.g., tables, fields) were defined and documented in a data dictionary and/or in Section 5 of a Federal Geographic Data Committee (FGDC)-compliant metadata file. Both spatial and non-spatial metadata records are uploaded to the NPS Integrated Resource Management Applications, where they are available to the public. All metadata records are updated as needed whenever additional data are collected and added to the data set.

5.6 Product Integration and Distribution

Multiple products are generated from this dataset: repeat photography, field and data summaries (short summaries of work completed), status and trend reports, and associated communication products (see Chapter 6). All data are assessed for sensitive content or proprietary purposes. All data, metadata, and reports judged to be non-sensitive and nonproprietary are made available to all interested parties. Other datasets, including those containing sensitive data, may be requested in writing from the data manager. Sensitive data are released only with a signed confidentiality agreement. Each network is responsible for ensuring that data are stored in the appropriate location and format and are obtainable by all person(s) interested and authorized to access the dataset(s).

5.7 Data Maintenance and Archiving

The project databases are archived on a secure server with regularly-scheduled backups. To ensure data compatibility with other existing or newly-developed software programs, each database table is exported to an ASCII file. These ASCII files are stored on a secure server drive. All archived files are designated as read-only.

Before revising the application or database schema, a backup of the current version is created to facilitate tracking of changes over time. The database schema is managed using version control software with changes being committed to the repository incrementally as schema changes are made. Once the current batch of changes is complete, the current repository state is tagged with the new version number. This allows applications that use the database to identify what compatible versions of the database schema. User applications follow a similar pattern with each release of the application being assigned a version number and containing a change log that tracks changes to that version of the application. When a new version of the application is released, frequent users of the data are notified of the updated version by data management staff.

After data have been certified and archived, they may be edited only under the following conditions: (1) changes must improve or update the data while maintaining data integrity, (2) all changes must be documented in the database change/version log, and (3) be prepared to recover from mistakes made during editing. Printed data records must not be altered; rather, they are reconciled to the database with the edit table. Any editing of archived data must be accomplished jointly by the project leader and data manager.

6. Reporting and Analysis

Reporting and analysis for springs monitoring consists of three tiers: (1) end of season descriptive field and data summaries (park- and protocol-specific); (2) annual climate and water resource status reports for Sonoran Desert parks (park-specific, multiple protocols); and (3) detailed status and trends reports on roughly 5-year intervals (park- and protocol- specific).

6.1 Analysis

As described in Section 3, monitoring occurs at "sentinel springs," which is similar to a judgmental or targeted design. Therefore, inference to the entire population of springs at a park, network, or regional level is not possible. Each year, the Chihuahuan Desert Network physical scientist/ecologist and Sonoran Desert Network aquatic ecologist determine the appropriate data analysis techniques and apply them to each monitoring parameter. As the data from each sampling season is certified, network scientists assess the data and consider if meaningful analysis can be conducted on the various parameter metrics of the protocol. Initial analytical efforts will assess the capacity to identify trend in hydroperiod of springs. Efforts will be made assessing the capacity of identifying trend in water quality (core parameters and major ions) as each season of data accumulates. Generalized linear mixed models may be the most appropriate approach to analyzing data for trend (Zuur et al. 2009). Changes to analytical techniques will be made in consultation with the network program managers and, if necessary, under the guidance of peer review.

The core water quality parameters and the major ion data from springs are analyzed using the most appropriate methods for the given data sets and will follow U.S. Geological Survey statistical methods (Helsel and Hirsch 2002). Initial analysis will be limited to basic summary statistics (calculating means median and estimates of variance). When the requisite number of samples have been collected (>5 years), it is likely that a Kendall Tau analysis (Zar 1999; Helsel and Hirsch 2002) will be initially considered; however, methods will not be limited to that particular analysis.

The persistence of surface water springs is estimated by analyzing the variance of temperature measurements taken every 1-2 hours by electronic data recorders placed in the spring orifice (Anderson et al. 2015). In preliminary analyses, a spring is considered "wet" if the daily variance is less than 20°C for consecutive days (variance threshold and R code based on Anderson et al. 2015). Otherwise, a spring is considered "dry." The total number of wet days and dry days are calculated for each water year and quarter. Additionally, the longest stretch of consecutive wet and dry days are calculated for each water year and quarter. We are working to verify the cut-off for differentiating "wet" and "dry" days through paired cameras at a few sites and with sensors placed in tubs at the Sonoran Desert Network. We are also exploring how to incorporate data from the sensors placed in nearby shrubs to help validate wet/dry determinations.

Wetted extent consists of three main parameters: length, width, and depth. During each visit, lengths up to 100m are measured with longer lengths placed into categories (100-200m, 200-500m, >500m). Median width and depth are calculated from the 10, 15, or 20 cross sections measured during the wetted extent field effort. In addition, the median particle size and detritus depth are calculated.

6.2 Field and Data Summaries

Upon completion of a field season, network staff submits a short, non-technical field and data summary to the corresponding park's Board of Directors member, Technical Committee member, or other designated representatives. These summaries are produced by network staff under the leadership of the network project lead. The purpose of these summaries is to highlight general ecological observations of interest or concern to park management, describe the field effort during the year and briefly summarize results. Highlights may include a water quality standard exceedance, observation of a previously undiscovered invasive non-native plant infestation or discovery of evidence of a new social trail or illegal border crossing. Field summaries are intended to quickly route important and interesting field observations to park staff without the delay of quantitative analysis and interpretation.

6.3 Sonoran Desert Network Annual Water Resource Reports

Springs information for Sonoran Desert Network parks are reported annually in park-specific Climate and Water Resources Reports. Climate and Water Resources Reports provide a snapshot of the status of springs, climate, groundwater (where applicable) and streams (where applicable) for the previous water year (October – September). Management assessment points (see Section 6.4) linking monitoring data to specific park management issues are presented and multi-year trends may be interpreted, where appropriate. The Sonoran Desert Network aquatic ecologist oversees the development and publication of these reports, in conjunction with other network staff and the field crew.

6.4 Status and Trend Reports

Every five years, or at an appropriate interval based on data analysis, the networks produce a series of park-specific status and trend reports. The protocol lead or program manager direct the production of this report, which involves network staff as well as external subject-matter experts when appropriate. The purposes of this report are to:

1. Describe the current conditions (status) and trends (if any) in spring ecosystem vital signs using univariate and multivariate time series analytical techniques, graphical techniques and (where appropriate) conceptual diagrams;
2. Interpret these conditions and trends in the context of other resources of interest and management objectives (see description of management assessment points below);
3. Explain the level of certainty upon which the data and interpretations are based and evaluate the effectiveness of the sampling design;
4. Use modeling and other data-exploration techniques to evaluate potential explanatory variables and covariates over broad thematic and spatial scales, and
5. Synthesize this wide-ranging information to explore patterns and better understand processes of spring ecosystems.

Management assessment points provide context and aid interpretation of ecological information in a management context. They do not define strict management or ecological thresholds, inevitably result in management actions, or necessarily reflect any legal or regulatory standard (Bennetts et al. 2007). In the status and trend reports, the authors describe spring-related natural resource management issues at a given park and propose a suite of management assessment points related to those issues. The issues, measures and assessment-point values are based on park documents, ecological literature and the authors' collective knowledge of these ecosystems.

Draft status and trend reports are reviewed by the corresponding park's representatives on the network's Board of Directors and Technical Committee for sensitive data and policy implications, per NPS Director's Order #66. If any reports include restricted data, only NPS personnel will have access to the full reports and the public will have access to versions without the restricted content. Final status and trend reports are submitted for publication in the NPS Natural Resources Report Series and/or peer-reviewed scientific publications. The report and derived-communication products (see Section 6.4) are served on the appropriate network website and the Science of American Southwest website (www.nps.gov/subjects/swscience/index.htm).

6.5 Additional Products

All annual and status and trend reports are available through the NPS Integrated Resource Management Applications, with links from the respective network websites. To reach broader audiences, including superintendents, interpreters and the interested public, additional communications products are derived from those published reports, including but not limited to two-page briefs and social media posts.

7. Personnel Requirements and Training

Ecologists/physical scientists and trained field staff are required for implementation of the arid-land springs monitoring protocol.

7.1 Roles and Responsibilities

7.1.1 Project Coordination and Oversight

The Chihuahuan Desert Network physical scientist/ecologist serves as the protocol lead and the Sonoran Desert Network aquatic ecologist serves as the Sonoran Desert Network lead. These positions work together to organize and oversee the springs monitoring effort in both networks. The protocol lead must have in-depth knowledge of this protocol and associated SOPs in order to successfully plan and execute field work and complete analysis and reporting requirements appropriately. The protocol lead and Sonoran Desert Network aquatic ecologist coordinate the project, review and update SOPs as needed, train the biological/physical science technicians, oversee the field effort and lead analysis and reporting.

7.1.2 Data Collection and Entry

Field data collection is conducted by crews consisting of biological science and/or hydrological technicians. The crew leaders report to and/or work closely with the Chihuahuan Desert Network physical scientist/ecologist and the Sonoran Desert Network aquatic ecologist. Crew leaders coordinate scheduling of field work with the protocol/project leads and park staff. The crew leaders and physical scientist/ecologist and aquatic ecologist share recruitment and training responsibilities for the field crew, including ensuring that the crew is sufficiently trained in all SOPs (see SOP 2).

Data entry and preliminary data QA/QC procedures are conducted by field technicians, including crew leaders, or other network personnel. Each network is responsible for entering and verifying its data. Data entry and QA/QC procedures are developed and refined by Southwest Network Collaboration data managers in cooperation with the protocol and project leads.

7.1.3 Data Quality Management

Southwest Network Collaboration data managers lead the development of data entry and QA/QC procedures, develop and maintain relevant databases and supporting data management systems, and manage both raw and processed information. The data managers must have in-depth knowledge of the data types and end-user requirements for the springs protocol. The data managers also ensure that SOPs associated with the protocol do not conflict with other plans, SOPs or guidance and are versioned appropriately. The Chihuahuan Desert Network physical scientist/ecologist and Sonoran Desert Network aquatic ecologist are responsible for validation and certification of data.

7.1.4 Analysis and Reporting

The Chihuahuan Desert Network physical scientist/ecologist and Sonoran Desert Network aquatic ecologist lead analysis and reporting for their respective networks and work together to apply appropriate analytical techniques. Crew leaders (see Section 7.2.1) work with the Chihuahuan Desert Network physical scientist/ecologist and the Sonoran Desert Network aquatic ecologist to produce field and data summaries (see Section 6.1) for their respective section of the protocol. The Chihuahuan Desert Network protocol lead and Sonoran Desert Network lead direct the development of status and trend reports (see Sections 6.3) with support from the network staff and cooperators.

7.2 Field Crew Qualifications and Training

7.2.1 Crew Composition

To facilitate effective, efficient data collection and equipment transport, field crews are ideally composed of at least two people: one crew leader (network biological science or hydrological technician) and one or more crew members. The experience level of the crew (i.e., the ability of each member to work independently or together for each sampling activity) dictates the ability of the crew to function optimally. The crew leader is responsible for assigning tasks to each person based on his/her expertise and the skills of the group as a whole.

7.2.2 Qualifications

The crew leaders, one for each network, should have experience collecting water quality and water quantity samples, including using multiparameter meters. The crew leader should have experience working in teams, preferably with experience leading teams, working independently, working in backcountry settings and be in good physical condition. S/he should preferably have experience using databases, spreadsheets and text-editing software to generate summaries of data and field efforts.

The additional crew members should have some experience collecting water quality and water quantity samples, identifying plant species and trouble-shooting equipment. Crew members should be in good physical condition, have some experience working in the backcountry and have the ability to work in a team.

7.2.3 Training

The crew leader for each network and/or the Chihuahuan Desert Network physical scientist/ecologist and/or the Sonoran Desert Network aquatic ecologist, attend the U.S. Geological Survey's course "Field Water-Quality Methods for Ground Water and Surface Water (QW1028TC)" or a similar training course. During the two-week course, instructors cover surface and groundwater sampling in both classroom and field environments.

Prior to data collection, crews should become familiar with this protocol and all SOPs and park-specific materials, such as invasive non-native plant-species lists and identification guides for invasive non-native and obligate/facultative wetland plants. Each person should be trained in all protocol-specific data collection methods, so that s/he can independently perform any necessary task. All field staff complete training in safety, use of electronic equipment (e.g., GPS units, water quality meters, cameras), field data collection procedures, navigation and data entry. The protocol and/or network lead provides training, and at their discretion, implement basic proficiency certification for staff involved with the spring ecosystems protocol. When possible, Chihuahuan Desert Network and Sonoran Desert Network field crews are trained together. The most critical skill for each monitoring module is knowledge of the equipment employed (e.g., water chemistry and flow meters) and the ability to perform accurate and consistent plant identification. Additional details on training are found in SOP 2.

The crew leaders are responsible for ensuring that all crew members read and understand the appropriate network safety plan prior to the field season. The network's Safety Plans and associated SOPs are located on the respective network servers. Where park safety procedures are more stringent than network safety procedures, park procedures are followed to ensure compliance with park guidelines and safety of crew members.

Training in wilderness first-aid and cardiopulmonary resuscitation (CPR) are strongly recommended for all crew members. At least one person, preferably the crew leader, should be currently certified in wilderness first-responder care. All crew members must be proficient with the use of and etiquette for provided communication devices, including park radios when available. At a minimum, each member receives training on how to adequately prevent environmental illness and injury, through Operational Leadership training, for example, as well as on team safety awareness.

8. Operational Requirements

Implementation of this protocol requires an annual work schedule and specialized field equipment, in addition to start up and annual expenditures.

8.1 Annual Schedule and Project Work Flow

The annual workload for this protocol consists of:

- Winter – kick-off meeting
- Spring – field data collection data verification
- Summer – data validation, close-out meeting, analysis and reporting, and
- Fall – continued analysis and reporting

The start-of-season kick-off meeting ensures coordination and smooth organization between field, data management and data analysis and reporting staff. The year-end evaluation and close-out meeting identifies any operational needs (e.g., revisions to SOPs, equipment repairs, updates to park species lists) and ensures that they are addressed in training and field-season preparation phase prior to the next data collection season.

Data for all modules (water quantity, water quality, site condition, and site characterization) are collected annually at each spring. Field sampling occurs from February through June, and visits in subsequent years should be scheduled as close to the same date as possible to improve repeatability.

The field season closes in July (or earlier) with a field-season close-out meeting, at which the status of the database is discussed and plans are made to complete the data QA/QC procedures so the data may be certified by the protocol and project leads. These tasks are completed through the summer.

8.2 Field and Facility Equipment Needs

Field equipment needs fall into four general categories: (1) site navigation and mapping instruments; (2) measurement equipment; (3) data entry and validation systems; and (4) safety and general camping equipment. Detailed equipment lists are attached to each field sampling SOP (3-8). Equipment costs are summarized in Table 10.

Site navigation and mapping requires an accurate GPS unit (two units per crew) and the skills to successfully operate them. Integrated handheld mapping units with GPS are best, as numerous shapefiles can be loaded and viewed, assisting in visualization and orienteering.

Measurement equipment includes:

- Multiparameter water quality meter to measure water temperature, pH, dissolved oxygen, and specific conductance,
- Field photometer for field water chemistry analyses,
- Temperature sensor or pressure transducer for measuring spring persistence,
- Digital camera for collecting photos, and
- Stopwatch, graduated cylinder and plastic bags for measuring flow.

8.3 Startup Costs and Budget

This protocol requires expensive and sophisticated equipment (e.g., multiparameter water quality meters) as well as simple and inexpensive equipment (Table 11). The equipment used in the springs protocol should be assessed annually for current effectiveness, and to evaluate the availability of any emerging or new technologies that may be cheaper or more accurate. The contracts for analysis of water quality samples sent to laboratories should also be assessed annually for costs and data quality. The Chihuahuan Desert Network physical scientist/ecologist and Sonoran Desert Network aquatic ecologist should be constantly looking for ways to make the program more cost-effective while still producing data of required accuracy and precision to achieve project goals.

Initial equipment costs (including several multiparameter meters) are estimated to be approximately $28,000 per network. Annual operating costs are significantly less, at approximately $5,000 per year per network for consumable supplies, such as calibration solutions and factory recalibration for key equipment.

The Southwest Network Collaboration may contract water chemistry analyses, at an annual cost of approximately $1,800 (Sonoran Desert Network) and $2,400 (Chihuahuan Desert Network).

Annual personnel costs per network are estimated at $86,500 (Table 11). This includes personnel for field and laboratory work, data management, analysis and reporting. Annual personnel costs are expected to incrementally increase.

Table 10. Partial list of equipment required for the springs monitoring protocol.

Module	Item(s)
Safety equipment	Safety equipment includes, but is not limited to: waders, personal flotation devices, first-aid kits, snake chaps and communication systems, such as satellite beacons, radios, satellite phones, and cell phones.
Water quantity	Stopwatch Graduated cylinder (1000 mL) Plastic bags Bucket Measuring tape Chaining pin Folding rulers (2) Temperature sensors (2) Pressure transducer (optional)
Water quality	Handheld multiparameter water quality meter Handheld optical dissolved oxygen instrument (optional) Bottles for water chemistry samples Field photometer Turbidimeter (Sonoran Desert Network)
Site characterization	Compass Clinometer GPS units (2), preferably one integrated handheld mapping units with mobile GIS GPS Digital camera (10-megapixel minimum resolution)

Table 11. Estimates for equipment, laboratory analysis, and personnel costs, costs are per network in 2017 dollars.

Cost type	Item	Startup	Annual cost
Equipment	Safety	$3,000	$2,000
	Water quantity	$5,000	$500
	Water quality	$15,000	$1,500
	Site characterization	$5,000	$1,000
	Site condition	$100	$50
	Subtotal	**$28,100**	**$5,050**
Laboratory analysis	Water chemistry	$2,400	$2,400
	Subtotal	**$2,400**	**$2,400**
Personnel	GS-6/7 tech (hydrology/vegetation) @ 10 PP (field work)	$20,000	$20,000
	GS-5 (hydrology/vegetation) or SCA intern @ 10 PP (field work)	$17,500	$17,500
	GS-11/12 data manager @ 10 PP (startup), 2 PP (annual) (data management)	$35,000	$7,000
	GS-11 physical scientist / ecologist @ 10 PP (analysis, reporting, project management)	$35,000	$35,000
	GS-11 writer-editor @ 2 PP (reporting)	$7,000	$7,000
	Subtotal	$114,500	$86,500
	TOTAL	**$145,000**	**$93,950**

Overall, startup costs for the springs monitoring protocol are approximately $145,000. Costs for subsequent years are estimated at $94,000. These initial costs do not include vehicle purchase and maintenance, computer IT assessments and training costs as these are understood to be available within the existing network infrastructure.

The expected lifecycle on the multiparameter meters is 10+ years with regular use and maintenance. Replacement costs should be scheduled to occur in a way that allows for meeting protocol objectives and recognizes budget restraints.

9. Revising the Protocol

This sampling protocol consists of the protocol narrative and 11 separate SOPs. The protocol narrative provides the history and justification for the program and an overview of sampling methods. The protocol narrative will be revised only if major changes are made. The SOPs, in contrast, are specific, step-by-step instructions for performing each task. They are expected to be revised more frequently than the protocol narrative and revisions will be coordinated between Chihuahuan Desert Network and Sonoran Desert Network.

Careful documentation of such revisions, including an archive of previous versions, is essential for maintaining consistency in data collection, analyses and reporting. To summarize changes, the monitoring database for each component contains a field to identify the protocol version used to gather and analyze data. The steps for changing any aspect of the protocol are outlined in SOP 10. The narrative and each SOP contain a Revision History Log that should be completed each time the narrative or an SOP is revised. The purpose of this log is to explain why changes were made and to track document version numbers. Former and active versions of the protocol narrative and SOPs are stored on separate drives on the respective network servers.

The networks use a Master Version Table and Version Key number (VK#) (see SOP 10) to track which versions of the narrative and SOPs are used in each version of the monitoring protocol. The VK# is essential if project information is to be properly analyzed and interpreted. ***The protocol narrative, SOPs, and data should never be distributed independently of the Master Version Table.***

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Appendix 1

Chihuahuan Desert and Sonoran Desert networks used a decision tree (Table A1; Figure 4 in Chapter 3) to prioritize springs as sentinel springs for monitoring in (based on Thompson et al. 2002; Sada 2013a; Sada 2013b; Weissinger et al. 2017). See Section 3.1 for additional details on spatial sampling design.

Table A1. Tabular representation of the decision tree used to prioritize springs as sentinel springs for monitoring in Chihuahuan Desert and Sonoran Desert networks (based on Thompson et al. 2002; Sada 2013a; Sada 2013b; and Weissinger et al. 2017).

Row	Parameter	Definition	If Yes	If No
1	Accessibility	Safe access, less than three hour hike and low theft potential	Proceed to row 2	Do not sample
2	Surface water present	Surface water observed during historic sampling or network inventory and monitoring efforts	Proceed to row 3	Do not sample
3	Repeatable measurement locations	One or more repeatable measurement locations for water quality and water quantity present	Proceed to row 4	Do not sample
4	Importance to park	Site has been described as important by park managers	Proceed to row 5	Proceed to row 6
5	Perennial water	Site has perennial surface water (estimated based on vegetation, macroinvertebrates, and temperature/persistence sensors)	Proceed to row 7	Proceed to row 8
6	Perennial water	Site has perennial surface water (estimated based on vegetation, macroinvertebrates, and temperature/persistence sensors)	Proceed to row 9	Proceed to row 10
7	Human alteration/ disturbance	Site has considerably been altered or disturbed by humans	Monitoring priority level 2	Monitoring priority level 1
8	Human alteration/ disturbance	Site has considerably been altered or disturbed by humans	Monitoring priority level 4	Monitoring priority level 3
9	Human alteration/ disturbance	Site has considerably been altered or disturbed by humans	Monitoring priority level 6	Monitoring priority level 5
10	Human alteration/ disturbance	Site has considerably been altered or disturbed by humans	Monitoring priority level 8	Monitoring priority level 7

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