ARIZONA SPRINGS

Springs Stewardship Institute
Museum of Northern Arizona

Desert Landscape Conservation Cooperative

Sky Island Alliance
Protecting our Mountain Islands and Desert Seas

Arizona Springs Restoration Handbook

Sky Island Alliance
and the Springs Stewardship Institute

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Table of Contents

Introduction

In arid landscapes, springs are biologically irreplaceable ecosystems. Emerging in many forms from aquifers, they serve as unique ecological indicators and windows into the Earth. Despite their relatively small geographical footprint, springs support more than 10% of the endangered species in the United States, as well as an enormous number of rare and/or endemic springs-dependent species. Springs are culturally significant to many indigenous cultures in the Southwest who view them as portals and places for training, rituals and the harvest of ethnoecological resources. Thus, springs play a vital role in the health and longevity of the region.

As land managers begin to recognize springs as important biological and cultural resources, they require systematic and comprehensive inventory, assessment and restoration protocols. This handbook is meant to advance the understanding of springs by land managers in the state of Arizona, as well as promote communication, stewardship, and collaboration, and to provide guidance to land managers embarking on springs stewardship programs. This handbook is intended to provide resource managers with background information regarding the nature of springs ecosystems, inventory and assessment protocols, and the tools necessary for effective restoration and monitoring. Our springs inventory, assessment, and stewardship protocols incorporates much previous research and practical, hands-on recommendations.

Together, with the support of the Sky Island Alliance (SIA), the Desert Landscape Conservation Cooperative (DLCC), and the Springs Stewardship Institute (SSI), land managers across Arizona can use this handbook to set measurable goals in their springs stewardship plans, and implement effective actions towards those goals.

Springs Stewardship Institute

The Springs Stewardship Institute (SSI) was established in 2013 as an initiative of the non-profit 501(c)(3) Museum of Northern Arizona (MNA) to advance the understanding and stewardship of springs ecosystems. SSI works towards this goal through research, stewardship, and collaboration to provide and share information related to these endangered ecosystems. SSI staff publish research papers, books, and guides to assist land managers with stewardship of their springs; much is available at http://springstewardshipinstitute.org/. SSI has developed inventory, assessment, and stewardship tools, and a secure online database of springs ecosystems that is available at http://springsdata.org/.

Springs
Stewardship Institute
Museum of Northern Arizona

Chapter 1 - Arizona Springs Ecosystems

Springs are biologically, culturally, and economically important in Arizona, the nation's second driest state. This chapter offers a detailed description of Arizona springs ecosystems, as well as how and why they are important to the overall environment.

Chapter 2 - Inventory and Assessment

Developing a springs restoration plan can be logistically and financially complicated. This chapter describes the steps necessary to conduct springs inventory and assessment in preparation for stewardship and monitoring restoration planning. This will assist land managers in prioritizing projects to make the most of restoration dollars, as well as providing comprehensive baseline inventory and assessment.

Chapter 3 - Springs-Dependent Species

Springs support a diverse array of life. From plants to invertebrates and vertebrates, springs are biological hotspots in arid landscapes, supporting many endemic, rare, or endangered species. This chapter provides background information on Arizona's many springs-dependent species.

Chapter 4 - Restoration Planning

Informed stewardship planning is based on a sound understanding of the site—its biota, ecological integrity, threats, and importance. This chapter, along with the supplemental worksheets, outlines restoration planning and gives an overview of the ongoing restoration and monitoring process.

Chapter 5 - Springs Restoration

Implementation methods vary depending on the springs type. This chapter provides case studies of four most common springs types in Arizona, and successful implementation and monitoring methods.

Chapter 6 - Monitoring

Monitoring and information management are essential for longterm site stewardship and rehabilitation; this process must be iterative. This chapter details the necessary elements of monitoring planning and implementation, and information management.

Sky Island Alliance

The Sky Island Alliance (SIA) is a non-profit 501(c)(3) in Tucson, Arizona that works to protect and restore the land, water, and biodiversity of the Sky Islands. Their scope spans the southwestern United States and northwestern Mexico, building partnerships and alliances, creating opportunities for hands-on conservation work, protecting open space, restoring healthy landscapes, connecting wildlife pathways, and inspiring wonder and understanding of the Sky Islands ecoregion. SIA has become a leading organization in connecting citizen science and conservation policy to achieve effective results. To learn more visit their website at: http://www.skyislandalliance.org/.

Chapter 1

Arizona Springs Ecosystems

Springs are ecosystems where groundwater is exposed at, and typically flows from the Earth's surface. Hydrologists, wetland technicians, and agency staff often describe "groundwater-dependent headwater wetland ecosystems", but here we will just call them springs.

Springs are fed by groundwater aquifers, and occur in many settings, both underwater as well as in terrestrial environments. Springs vary greatly in flow, water chemistry, geomorphic form, ecological significance, and cultural and economic importance (Springer et al. 2008). Seeps are simply small springs, usually with immeasurably diffuse or small seepage or flow.

English suffers from having at least three meanings for the word "spring" (i.e., season, mechanical device, and water sources), and languages with unique words for springs may have better appreciation of them (i.e., "source" in French, or "manantial" in Spanish). Also, in our experience, sources are usually multiple; therefore, we prefer to describe these features in the plural form as "springs" or "springs ecosystems".

While more obviously important in arid regions, springs in all landscapes are among the most productive and influential ecosystems. Springs provide many Arizona homes, ranches, farms, towns, and even some of its cities with domestic, commercial, and livestock water. Springs support a high proportion of the state's rare and unique wetland plants, invertebrates, fish, and animals, as well as a host of rare, poorly known species and many upland species. In addition, springs are paleontologically, culturally, historically, and socioeconomically important.

As many Arizona ranches, farms, towns, and some cities were founded on springs, many have been intensively used for human purposes. Although most springs in Arizona are ecologically impaired, if the aquifers that support them are intact (often the case in mountainous areas), springs are remarkably resilient and can be readily managed for sustainable human and natural functions. We hope this handbook will encourage more sustainable stewardship of these remarkable ecosystems.

Arizona Geology

Arizona straddles the boundary between two vast geologic provinces (Fig. 1.01), and thus has characteristic features of both. Northern Arizona lies on the Colorado Plateau, which occupies 373,000 km^2 (144,000 mi^2) of the Four Corners states and Wyoming. It extends south to the Mogollon Rim and includes the White Mountains. The Plateau contains several dozen horizontally bedded strata, consisting of impermeable clay, shale, and mudstone beds (aquitards that restrict groundwater flow), as well as thick sandstones and limestone beds that serve as aquifers. Igneous strata are abundant on top of the Plateau and also occur as buried strata; those on the surface function as shallow aquifers. The deepest strata on the Colorado Plateau are crystalline basement metamorphic rocks—the schists, granites, and gneisses exposed in the Inner Gorge of Grand Canyon. Some of these deep strata bear what may be the oldest groundwater in the Southwest, waters that are warm and enriched with minerals.

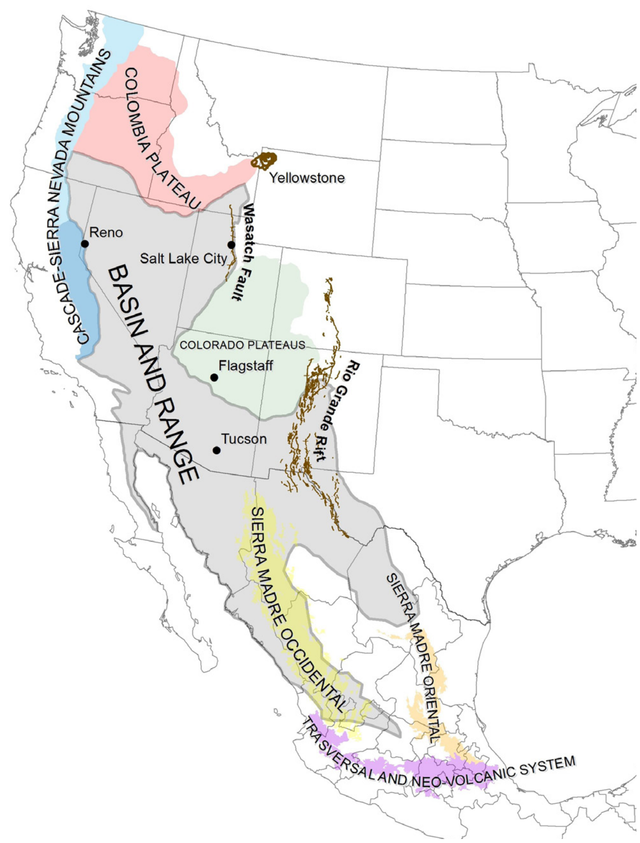
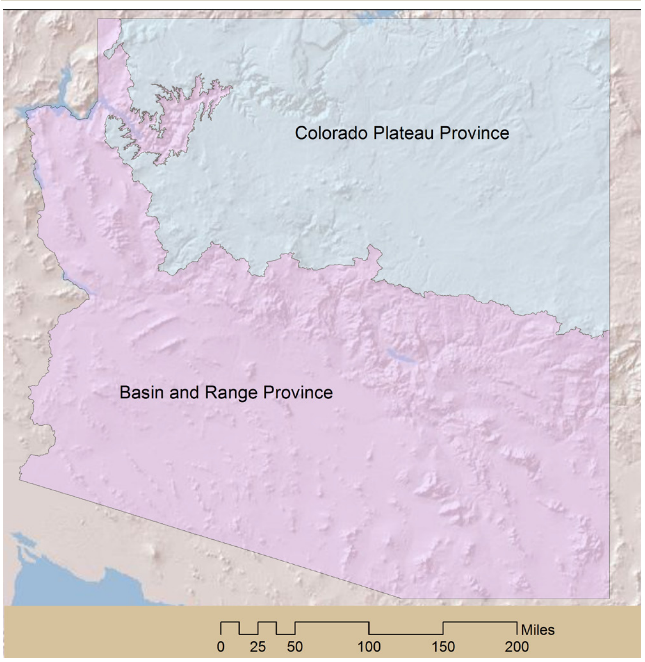


Fig. 1.01. (Above) Map of geological provinces in Arizona and the Great Basin © Samantha Hammer, SIA. (Below) Colorado Plateau and Great Basin Provinces in Arizona, SSI.



In contrast, central and southern Arizona lie in the Basin and Range geologic province. This 20+ million year-old mountain building event is the result of the Earth's crust being pulled apart, a tectonic process geologists call extension. The vast Basin and Range province extends from southeastern Oregon, eastern California, Nevada, western Utah, southern Arizona and New Mexico, and southeastward into Texas and northern Mexico. This province is dominated by fault-block, horst and graben mountain ranges with intervening valleys. As a result, it is characterized by many mountain ranges that in Arizona are mostly aligned to the northwest.

Arizona Aquifers

Arizona springs waters emerge from aquifers—bodies of rock with interstitial space and/or fractures that hold water (Fig. 1.02). The water in aquifers is nearly all derived from precipitation, particularly from upland snowmelt in the winter and intense summer rains that saturate the soil, and allow water to infiltrate down to the aquifers. A tiny percent of groundwater is derived from degassing of the Earth's crust: connate water that discharges upward into the aquifer (Crossey et al. 2012).

The size, structure, and water quality of Arizona aquifers vary in relation to the bedrock geology, depth, and the distance and duration of groundwater's flowpath between the state's two geologic provinces (Fig. 1.01). The Colorado Plateau contains stacked and perched aquifers, some of which are the largest in the state (i.e.,

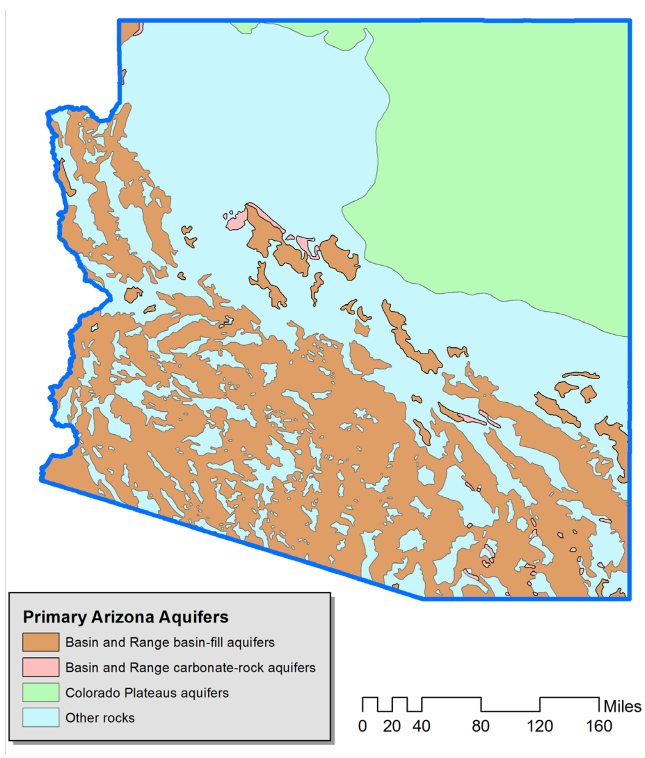


Fig. 1.02: Map of principal shallow aquifers of the Arizona. Data published by the U.S. Geological Survey (2003).

the Little Colorado River basin and the Kaibab Plateau). In contrast, the Basin and Range portion of the state contains many small aquifers on the mountain ranges, and larger valley fill aquifers in the basins that support our major cities. Flowpaths in both provinces can be very brief (a few days), but may range up to 13,300 years (Monroe et al. 2005; Johnson et al. 2012). Generally, spring water derived from longer and deeper flowpaths is warmer and higher in mineral content and lower in potability (Fig. 1.03).

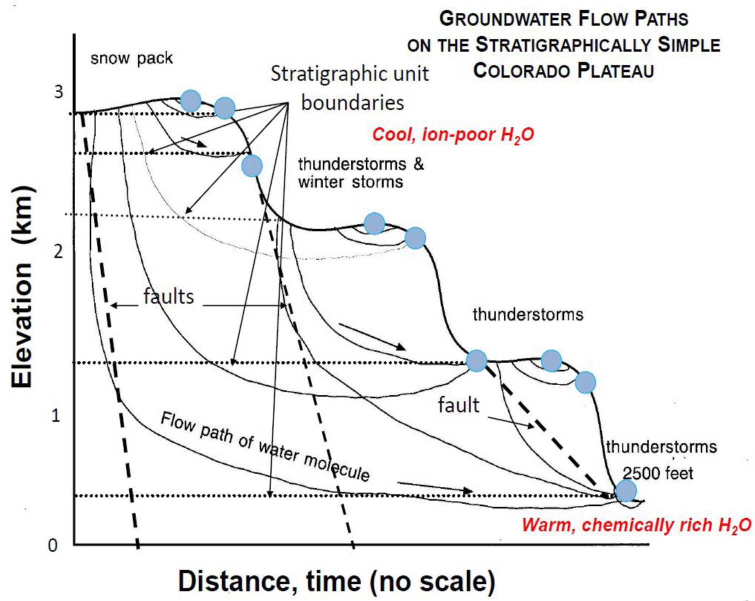


Fig. 1.03: Aquifer flowpaths, springs emergence, and general water quality characteristics of springs on the Colorado Plateau (modified from Grand Canyon Wildlands Council 2002).

Arizona Springs Distribution

Springs are abundant features of the landscape. Using density of springs from the United States, SSI estimates that 500,000 to one million springs occur in the contiguous United States, and perhaps 50 million springs may exist across the world; however, springs are unevenly distributed.

Springs in the United States are most abundant in complex terrain, where the edges of aquifers are exposed. They are rarest in plains and flatland landscapes, such as the Great Plains and the Central Valley of California. They tend to be less common in valleys and on the floodplains of large rivers. In all landscapes, springs are poorly and incompletely mapped: improved mapping of springs is usually the first order of business.

Arizona, the nation's second driest state, has the highest known density of springs, with more than 10,000 in SSI's online database, and nearly 0.02 springs/km^2 (Fig. 1.04). Arizona springs are most abundant in montane and canyon-bound areas, such as the Sky Islands, the Mogollon Rim, and Grand Canyon regions, and springs are less common in flatlands, such as the southwestern quarter of the state.

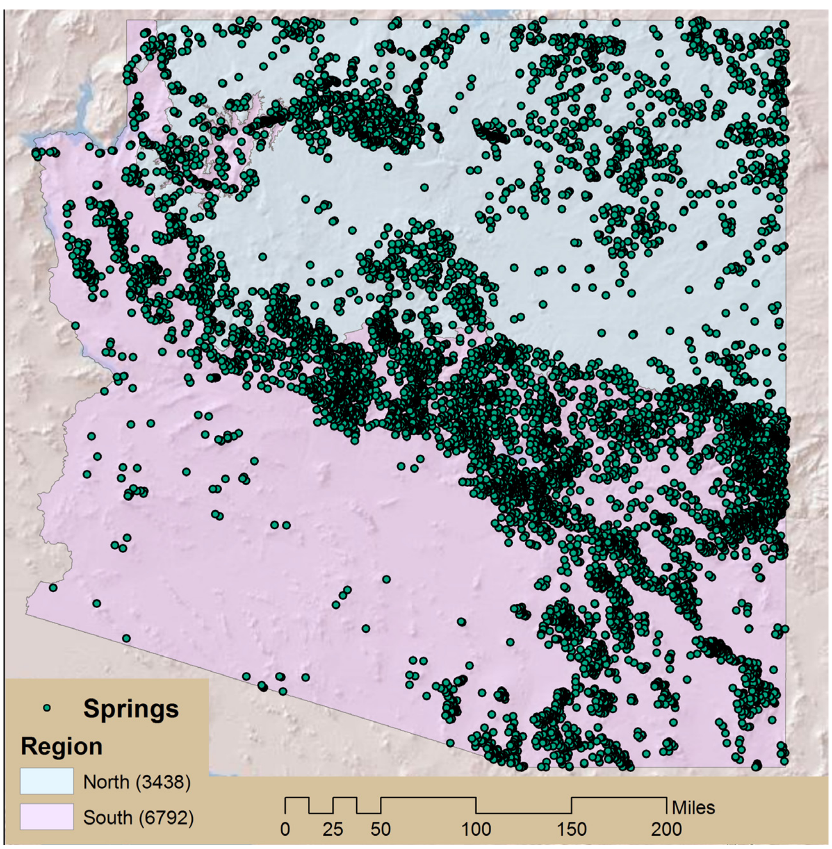


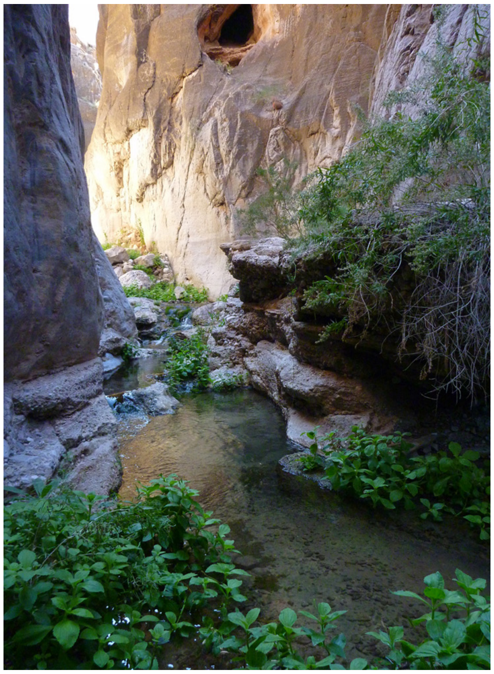
Fig. 1.04: Known springs of Arizona currently available at Springs Online (http://springsdata.org/). Data are compiled from multiple sources, including the USGS NHD and Geonames databases, the Arizona State Land Office, federal and state land managing agencies, NGO organizations, independent researchers, topographic maps, and publications.

Springs Flow and Water Quality

Water quality of Arizona springs varies widely in relation to flowpath (Fig. 1.03). Springs emerging from basalt aquifers at high elevations with relatively short flowpaths typically produce cold, low mineral content water. In contrast, springs with long flowpaths often produce warmer or rarely hot, highly mineralized, travertine-depositing water that emerges at low elevations (e.g. along the lower Little Colorado River, in Fossil Creek in the Verde Valley). Arizona has only a few hot springs (e.g., Arizona, Castle, and Verde Hot Springs; Waring 1965), most with long histories of modification as resorts. While naturally arising, such highly mineralized waters generally are neither palatable nor safely potable. The biota occurring in highly mineralized springs water often are closely adapted to it. As a result, tightly restricted (endemic) species are unique to springs with long flowpaths.

Flow, but not water chemistry varies widely between the state's two geologic provinces (Table 1.01). Summing the total discharge from 1,342 Arizona springs that have been measured, and adding 5,221 liters per second (L/sec) of springs-contributed baseflow from major Colorado River tributaries, the state's springs contribute at least 17,176 L/sec of flow (4,537 gallons/sec). This equals 542 billion L/year (439,500 acre-feet/year), representing roughly 6% of Arizona's 2012 water usage, and 16% of Arizona's Colorado River annual allotment. Springs in the Colorado Plateau portion of Arizona contribute 84% of the springs discharge for the state; however, overall water quality is similar between Arizona's two geologic provinces.

Aquifer pollution that affects springs is still relatively rare in Arizona, although contaminant-laced surface waters, such as mining wastes and urban reclaimed water are finding their way into some of the state's aquifers.



Pristine springs in Grand Canyon, Arizona. Photo courtesy of Rich Rudow © 2015.

Table 1.01: Summary of Arizona springs flow, temperature, pH, and specific conductance by geological province. Data were exported from Springs Online (http://springsdata.org/) on 1/2/2016. No hot springs are included in this analysis. CI = confidence interval, N = sample size, SC = specific conductance.

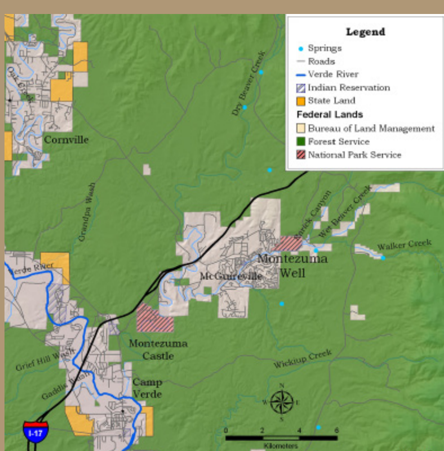
Arizona Geological Province	Mean Flow (L/sec) (Median; 95%CI; N)	Mean Temp (°C) (95%CI; N)	Mean pH (95%CI; N)	Mean SC (µS/cm) (95%CI; N)
North (Colorado Plateau)	27.9 (0.12; 13.97; 744)	18.2 (6.37; 426)	7.6 (0.07; 426)	635 (97.1; 426)
South (Basin and Range)	9.7 (0.19; 5.79; 598)	17.6 (0.8; 280)	7.5 (0.9; 280)	607 (117.1; 280)
All Arizona	19.8 (0.14; 8.18;1342)	18 (3.84; 706)	7.6 (0.5; 706)	624 (74.6; 706)

Montezuma Well

Arizona Heritage Waters

Montezuma Well.
Molly Joyce photo © 2015.

Montezuma Well has the highest concentration of endemic (unique) species at any point we know of in North America.
To find out more about this spectacular example of high biodiversity, read the full report at Arizona Heritage Waters, from Northern Arizona University. http://www.azheritagewaters.nau.edu/loc_MontezumaWell.html



Montezuma Well, located in the Upper Verde River watershed, is just off of I-17. Map by Chris Brod, courtesy of Arizona Heritage Waters.

Springs as Ecosystems

Ecosystems are groups of species co-occurring in and interacting with their physical habitats. At a coarser scale, ecosystems in a region are grouped into biomes that support relatively discrete assemblages of plants and animals. The major biomes of Arizona include: Chihuahuan Desert, Sonoran Desert, Madrean Archipelago, Mojave Desert, the southern Colorado Plateau, and the AZ-NM Mountains.

Springs ecosystems are unusually self-contained, making them ideal for the study of ecosystem ecology (Odum 1957, Blinn 2008). Springs are structured by physical interactions among geology, hydrology, and climate, and emerge as the result of geologic structure and aquifer mechanics (Fig. 1.05). At their sources, springs ecosystems are strongly influenced by geomorphology and microclimate, as well as the disturbance regime and microsite productivity. All of those physical factors affect the development of microhabitats and soils. Springs are colonized by actively and passively dispersing species, generating the biological assemblage one encounters during a site visit. This assemblage varies over time (e.g., daily, seasonal, interannual periods), naturally and because of human activities. Exploitation of ecosystem goods and services affects the biological assemblage and the microhabitats that the springs support.

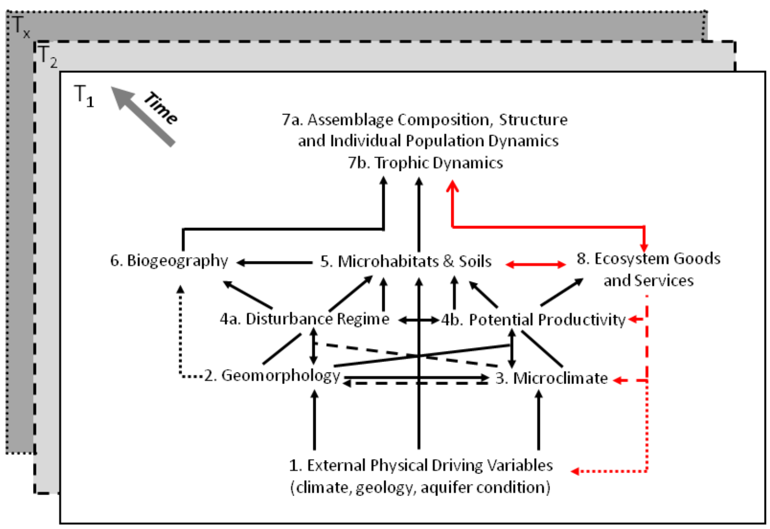


Fig. 1.05: Springs ecosystem conceptual model modified from Stevens and Springer (2004). Dashed arrows reflect indirect influences, while red arrows indicate human impacts.

Springs Types

Effective stewardship requires understanding the status of groundwater supply, and the type and context of the springs (Scarsbrook et al. 2007). Springer and Stevens (2008) identified 12 types of spring (Figs. 1.06 and 1.07) that include lentic (standing water) and lotic (moving water) springs.

Lentic Springs Types

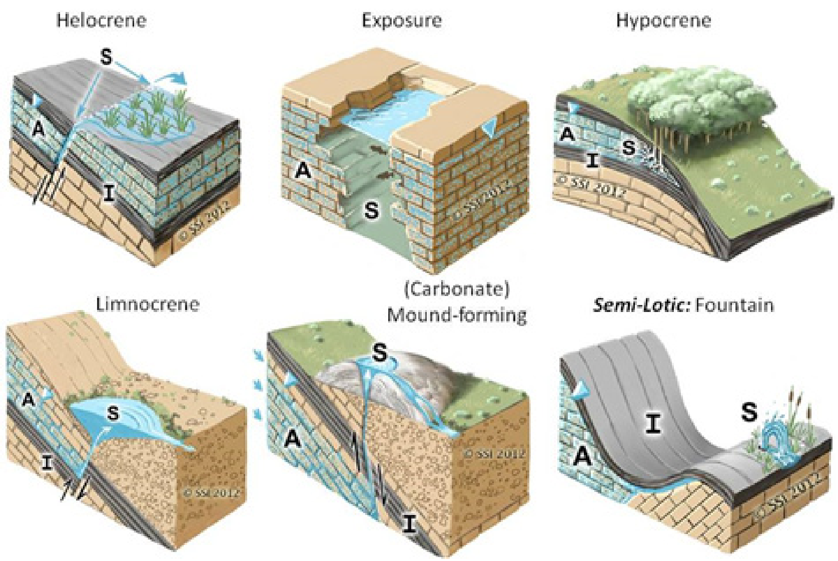


Fig. 1.06: Lentic springs types, with A=aquifer, S=source, and I=impermeable layer, illustrated by V. Leshyk for SSI © 2012).

Exposure springs occur where a water table is exposed, without flowing, at the Earth's surface.

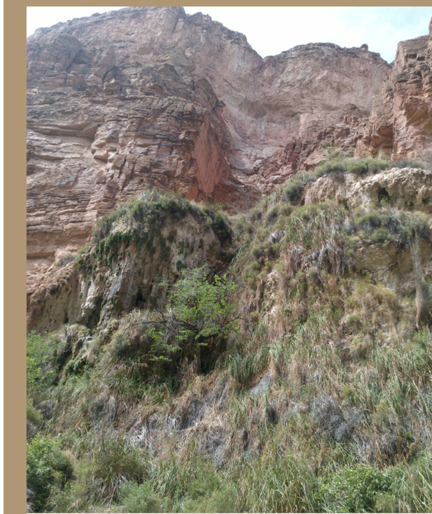
Fountain springs (semi-lotic) are those where artesian upwelling causes flow to rise higher than the surrounding landscape.

Helocrene springs are springfed wet meadows, called ciénegas at elevations up to about 2,135 m (7,000 ft), or groundwater-fed fens at higher elevations.

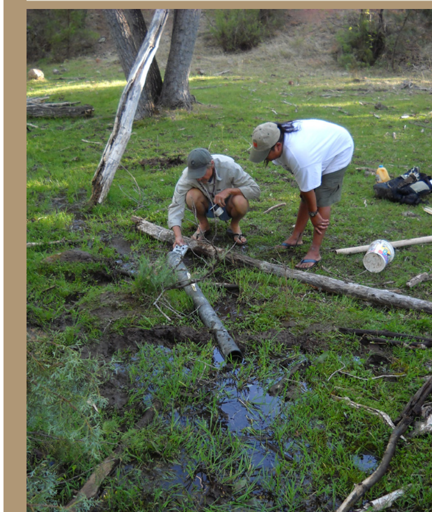
Hypocrene springs occur where groundwater is not expressed at the Earth's surface, but shallow groundwater is discharged by transpiration through wetland vegetation.

Limnocrene springs emerge into a open pool of water.

Mound-forming springs form where elevated calcium carbonate concentration deposits travertine. This type also forms in the arctic where ice builds up, forming pingo ice hills or aufeis ice sheets.



Carbonate mound forming Grand Canyon National Park, Arizona.



Helocrene (marsh forming) Apache-Sitgreaves National Forest, Arizona.

Limnocrene (pool forming) L.O. Spring, Kaibab National Forest, Arizona.

Gushet
Vaseys Paradise, Grand Canyon National Park, Arizona.

Rheocrene
Bear Spring, Kaibab National Forest, Arizona.

Hillslope
Two Tree Springs, Grand Canyon National Park, Arizona.

Lotic Springs Types

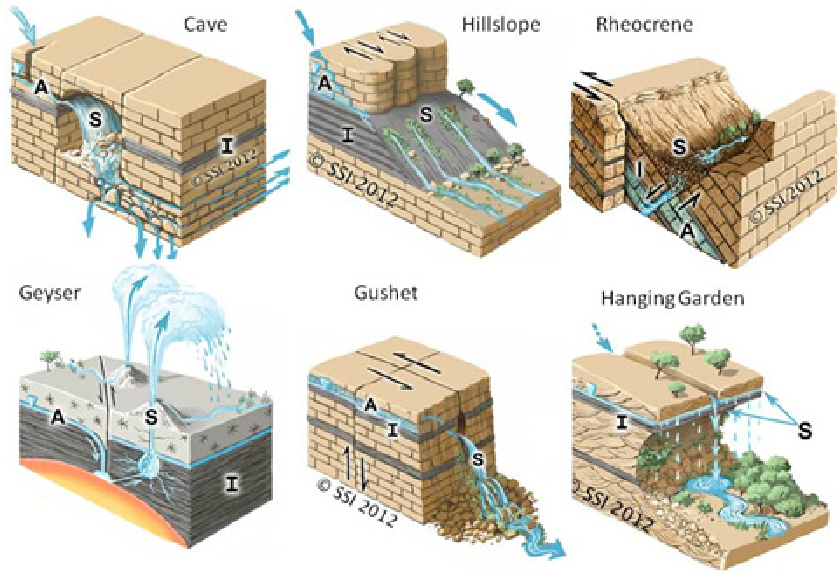


Fig. 1.07: Lotic springs types, with A=aquifer, S=source, and I=impermeable layer, illustrated by V. Leshyk for SSI © 2012).

Cave springs emerge within a cave and flow into the surrounding landscape.

Geyser springs are those where groundwater is forcibly erupted from the Earth by steam build-up because groundwater is being super-heated by contact with magma, or by carbon dioxide build-up from carbonate-laden groundwater. These are not found in Arizona.

Gushet springs emerge as focused flow cascades from nearly vertical cliffs.

Hanging garden springs usually emerge as seepage along a horizontal fracture or contact where an aquifer lies atop an impermeable stratum, such as shale, clay, or mudstone layer.

Hillslope springs occur where groundwater emerges on gently to relatively steeply sloping (15-60°) land, with or without focused flow.

Rheocrene springs emerge into a channel that extends well upstream from the springs source. This springs type may be subaqueous, emerging below the surface of a stream. Rheocrene springs are commonly subject to regular surface-flow flooding.

Fig. 1.08: Hidden Spring, Grand Canyon. This is an example of a combination of two spring types—a rheocrenic hanging garden. The spring emerges from the contact between geological layers as a hanging garden, but the emergence is within a channel. Photo courtesy of Rich Rudow © 2015.

Not included in this list are paleosprings that flowed in the recent geologic past (e.g., the Pleistocene or early Holocene) but no longer do so. Paleosprings usually occur as travertine mounds (e.g., along Highway 180 south of St. Johns, along the Little Colorado River), or exposures of fossilized peat.

Many springs exhibit characteristics of two or more springs types (Fig. 1.08). The array of springs types in Arizona varies between the two geologic provinces of the state (Fig. 1.01). Hillslope springs are most common across the state, but southern Arizona spring types are co-dominated by rheocrene springs, while northern Arizona on the Colorado Plateau is co-dominated by hanging gardens. Limnocrene springs are rare in the state, but some support many endemic species (e.g., Montezuma Well, Quitobaquito, and Medicine Springs). Helocrene springs (wet meadows springs) were once abundant throughout the state, with low elevation springs called ciénegas and higher elevation sites called groundwater-dependent fens. Due to extensive draining and management for livestock and agriculture, helocrenes are now among the most critically endangered ecosystem types in the Southwest (Henderson and Minckley 1984).

In the Basin and Range geologic province in the southern half of Arizona, the array of springs types is

Rheocrene >> Hillslope > Helocrene > Others

whereas on the southern Colorado Plateau in northern Arizona the array of springs types is

Rheocrene = Hillslope > Hanging Garden = Helocrene > Others

among 724 springs for which data were available (Fig. 1.09). The proportion of hillslope, helocrene and hanging gardens springs is much higher on the Colorado Plateau than in the Basin and Range province in Arizona, reflecting the different geologic and tectonic structure of the two provinces. Also, the proportion of limnocrene springs is relatively small in both provinces (4.6-6.4%). Geysers are the only springs type that is not found in Arizona.

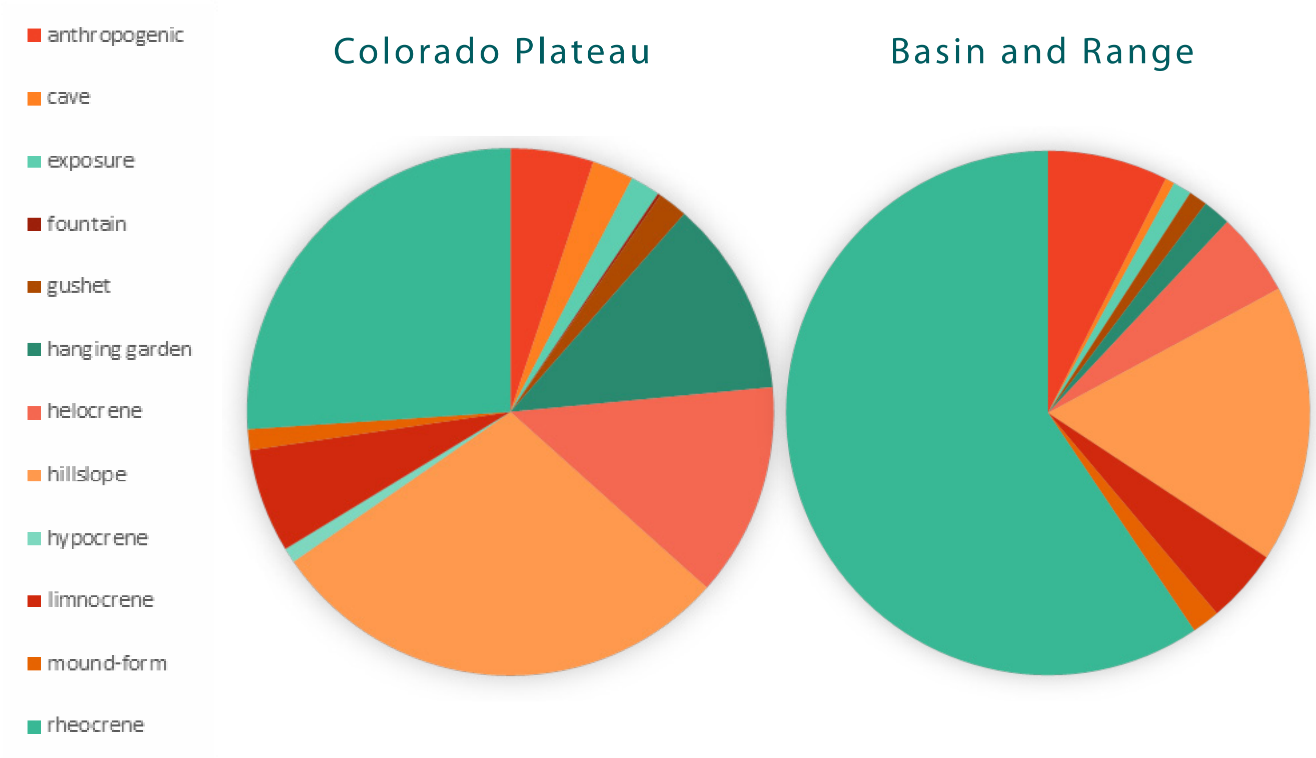


Fig 1.09: Springs vary by type across the a) Colorado Plateau (N-549) and b) Basin and Range (N = 175) geologic provinces in Arizona. The proportion of anthropogenic springs, those with geomorphology entirely altered by humans, is about equal in the two provinces (5.1-7.4%).

Springs Microhabitats

Springs are complex ecosystems not only because of the large array of types, but also because each springs ecosystem may include several to many microhabitats, with each microhabitat supporting its own array of landforms, soils, and plant and animal species (Figs. 1.10 and 1.11).

A dozen microhabitat types are associated with large springs: caves, dry and wet wall surfaces, colluvial slopes, madicolous cascading flow, spray zones, wet meadows, pools, flowing channels and terraces, and hyporheic zones (Table 1.2; Fig. 1.8). Springs microhabitat diversity is positively related to the number of plant species (Sparks 2014; Springer et al. 2014), and likely to invertebrate diversity. Thunder River, a large gushet springs ecosystem in Grand Canyon (Fig. 1.10) supports 10 microhabitats and the highest density of landsnail species known in the Southwest (Spamer and Bogan 1993). Thus, biological diversity of a springs ecosystem is related to the mosaic of microhabitats that occur there. The success of springs ecosystem rehabilitation depends on clearly defining the desired microhabitat array, including the area of each microhabitat desired.

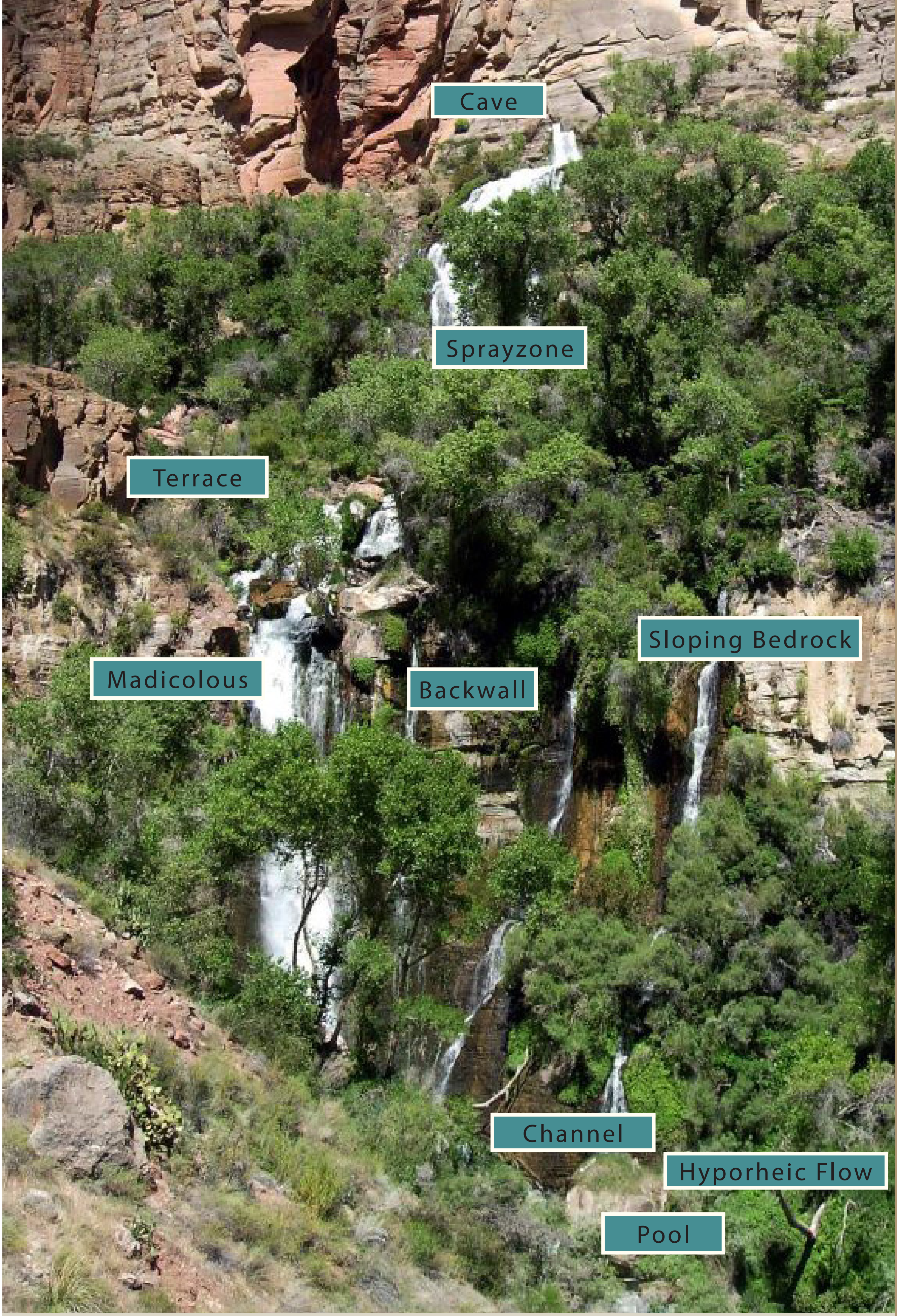


Fig 1.10: Thunder River Springs microhabitats, Grand Canyon National Park, Arizona.

Microhabitat Type	Springs Type: Cave	Exposure	Fountain	Geyser	Gushet	Hanging Garden	Helocrene	Hillslope	Hypocrene	Limnocrene	Mound-form	Rheocrene
Backwall	□	□	□	□	▒	■	□	□	□	□	□	□
Sloping bedrock	■	■	□	▒	■	■	□	▒	▒	▒	■	▒
Cave/tunnel	■	□	□	■	▒	□	□	□	□	□	□	□
Channel	▒	□	▒	▒	■	■	▒	▒	▒	▒	▒	■
Low gradient cienega	□	□	■	▒	▒	□	■	■	▒	▒	▒	□
High gradient cienega	□	□	▒	▒	▒	▒	□	■	▒	▒	▒	□
Colluvial slope	▒	▒	▒	□	■	■	▒	□	▒	■	▒	▒
Hyporheic zone	□	□	▒	□	▒	▒	▒	▒	▒	▒	▒	■
Madicolous flow	▒	□	□	▒	■	▒	□	□	□	□	▒	▒
Spring mound	□	□	▒	▒	□	□	□	□	▒	▒	■	□
Pool	▒	▒	□	▒	▒	■	□	□	□	■	▒	▒
Pool margin	▒	▒	□	▒	▒	■	□	□	□	■	▒	▒
Sprayzone	□	□	□	▒	▒	▒	□	□	□	□	□	▒
Terrace	▒	□	□	▒	■	■	▒	▒	▒	▒	▒	■
Other	□	□	□	□	□	□	□	□	□	□	□	□

■ Microhabitat is commonly found in this springs type

▒ Microhabitat may occur in this springs type

□ Microhabitat is not usually associated with this springs type

Fig 1.11: Fourteen or more microhabitat types may occur at some of the twelve springs types. Microhabitat diversity is related to biological diversity. Thus, gushets and hanging gardens where microhabitat diversity is higher often support more species than others (e.g. exposure springs).

Human Impacts on Springs

Humans evolved at springs (Cuthburt and Ashley 2014), and in the Southwest humans have intensively used springs for millennia to ambush prey, for harvesting plants and minerals, and for agriculture (Haynes 2008). However, modern human uses of springs have become far more complex and the scale of impacts has expanded, including groundwater pumping, flow diversion and irrigation, mining, livestock husbandry, forestry, air and light pollution, recreation, nonnative species introduction, and other direct and indirect uses. Many of these impacts are ubiquitous, occurring across broad regions and at most springs types.

Impacts on aquifers and groundwater quality range from none to complete dewatering of the springs, resulting in substantial alteration of springs microhabitats, vegetation composition and cover, faunal occurrence and distribution, and increased abundance and role of invasive species. Removal of groundwater through pumping near springs sources reduces or eliminates surface expression of flow, jeopardizing ecosystem structure and function. In contrast to regional effects, some kinds of impacts are more common at specific springs types. For example, gravel mining is most common in stream-channel rheocrenic settings, while trenching, flow focus, and excavation are common practices at marsh-forming helocrene springs (Fig. 1.12). Both general and specific types of impacts are important because springs often serve as keystone ecosystems, and the loss of springs can reduce the ecological integrity of adjacent upland ecosystems. Because human use of Arizona springs extends back to the Pleistocene epoch, springs restoration planning and execution should include consideration of human use as well as ecological sustainability.

Post-emergence impacts on springs include: flow diversion; livestock watering, recreational facilities; inappropriate fencing; pond creation; water pollution (e.g., from livestock watering); and accidental or intentional introduction of nonnative species. Flow capture at the source is required by state and Environmental Protection Agency (EPA) policy to ensure that groundwater used for domestic purposes is not contaminated by exposure to the atmosphere. Impacts at the sources of springs ecosystems include partial or complete diversion and the construction of springs boxes (Figs. 1.13 and 1.14). However, this practice eliminates the source area—the most biologically important habitat of the springs ecosystem. Instead of extracting all surface water, flow splitting can be used to ensure some flow emerges at the source area, while still providing unexposed groundwater for human consumption (Fig. 1.15). Thus, springs restoration requires careful forethought: well-intended practices like fencing to exclude livestock may backfire as vigorous wetland vegetation growth can consume surface water habitat needed by aquatic biota (e.g., Kodrick-Brown and Brown 2007).

Fig. 1.12: This spring was excavated to form a tank that has been heavily grazed by livestock and an overabundance of elk.

Fig 1.13: This spring was excavated and boxed long ago. The piping is no longer functional, so the flow pours out onto the ground.

Flow Splitting

Flow splitting allows flow to emerge at the source while providing water downstream for human purposes. Flow splitting involves several approaches, including pre-emergence and post-emergence technologies. For the former, a springs source can be excavated and fitted with piping and a valve-controlled flow splitter to regulate how much water emerges at the source and how much is diverted. Post-emergence flow splitting can be accomplished by establishing a stilling pool and installing piping with a valve to regulate discharge. If the piping is directed into a trough or tank, the tank can be fitted with a stop valve system (like that in a toilet) to keep the trough full but stop excess flow into the trough.

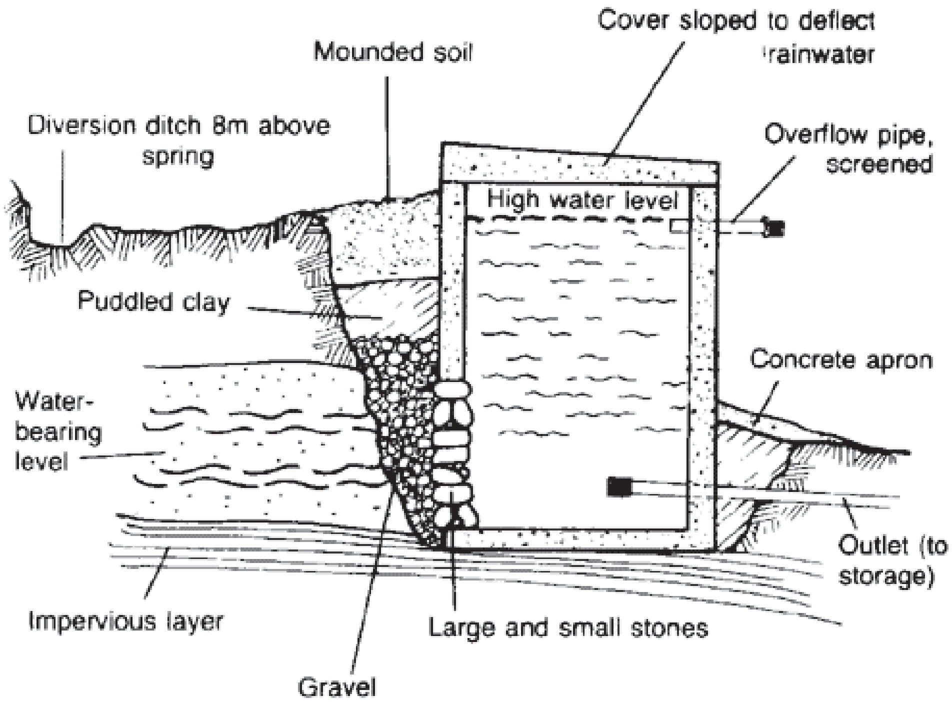


Fig. 1.14: Diagram of a typical spring box excavated into a hillslope spring. Various types of spring boxes have been constructed, depending on the geomorphology of the site and the type of spring. Unfortunately, this construction typically obliterates the source area. Diagram courtesy of http://www.clean-water-for-laymen.com/.

Fig. 1.15: An example of flow splitting at Horse Spring, Apache-Sitgreaves National Forest. A pipeline draws water from the source to a hand-carved wooden trough. Flow splitting draws animals to the trough for water, protecting the source of the spring. Photo by Molly Joyce © 2015.

Indigenous Values

The contemporary US environmental perspective is that humans can only degrade the natural world. In contrast, Asian, Native American, and likely other indigenous cultures consider humans to play an essential role in improving the quality of Nature. The role or responsibility of humans in this "man-in-nature" philosophy is stewardship of the Earth's natural resources. Native cultures in the American Southwest regard springs as sacred landscape features, emerging from the Earth through a living, divine process that links the Earth to the heavens. For those Tribes, springs serve as sites at which key resources are gathered, places where youth are taught cultural lessons, and historically significant spots or stopping points along routes through the landscape. But springs also are places where clans or entire cultures are considered to have emerged onto the Earth's surface, or sites that are comparable to purgatory or heaven. There are some analogues of these beliefs in Western European culture: springs in both Europe and North America are places where miracles and healing occur. However, Western culture largely regards springs and springs water as economic commodities and property, and the loss of springs through groundwater depletion is collateral economic damage, sacrificed for the greater good of water supplies management. Nonetheless, the wide array of indigenous values associated with springs, values for which the Western culture has little understanding, can vastly complicate restoration/rehabilitation and monitoring efforts, and require earnest consultation with Tribal elders. If regional Tribes claim affinity with a spring, it is helpful to know what cultural information is available and to seek advice from Tribal elders on springs management.

Restoration vs. Rehabilitation

Restoration of an ecosystem to its pristine condition prior to human intervention is impossible, and the use of this concept is flawed for several reasons. First, returning the flow, landforms, and biological assemblages that existed at a spring in the past requires full understanding of the range of natural variation in all associated ecosystem variables, and such

Fig. 1.16: Grassy Spring, Arizona Strip. Photo by Grand Canyon Wildlands Council.

Indigenous Values

- Springs are viewed as the point of origin for many tribes and cultures, where life began.
- Springs are the sites for many cultural ceremonies and rituals among tribes such as the Hopi.
- Springs are places where youth are taught cultural lessons. For example, the tradition of Hopi runners took young members of the tribe to each spring where they would tend crops, collect water, and maintain the integrity of the spring.
- Springs support traditional terraced gardens, providing irrigation for crops in the arid Sonoran Desert.
- Springs are sites where key resources are gathered: medicinal herbs, edible plants, and fresh water.
- Springs served as historical waypoints for various tribes living and moving across Arizona and the southwest.

monitoring data do not exist. Second, even if those data did exist, using them to recreate past conditions is simply not feasible. Third, humans have used all large springs ecosystems since the Pleistocene here in Arizona: there is no such entity as a springs ecosystem that has not sustained significant anthropogenic impacts, and no such thing as a pristine springs ecosystem.

Nonetheless, ecological rehabilitation and environmental reconciliation of springs can be achieved, as long as the aquifer supplying flow is minimally altered. While this is a significant issue around large urban areas or regions with intensive groundwater extraction, many of the state's aquifers are small and relatively unaffected by pumping. Springs in those settings can be rehabilitated successfully and provide benefits for wildlife, recreation, and keystone ecosystem functionality.

Climate Change and Adaptation

Climate changes stand to alter precipitation and groundwater infiltration in the Southwest, and strategies for adaptation to climate change are receiving much consideration by water managing agencies, such as the Bureau of Reclamation (e.g., U.S. Bureau of Reclamation 2012). For those springs with intact aquifers, improved stewardship that includes rehabilitation of ecological and refugial functionality of the springs can help maintain species that may otherwise lose their habitat under increasingly desertic climates. In regions with declining groundwater tables, aquifer restoration actions may be needed to regenerate springs, streams, and groundwater-dependent wetland habitats. Actions such as groundwater banking or intentional recharge may buffer change, not only by protecting water supplies from evaporation but also by recharging springs flow and habitats.

Benefits of Springs Rehabilitation

Provided that the aquifer is relatively intact, springs are among the most easily restored and sustainable of ecosystems, providing water and natural resources for humans while recovering much ecological integrity (Burke et al. 2015, Fig. 1.17). Springs restoration efforts are often successful (Davis et al. 2011), and many advantages may accrue, with both short-term and long-term benefits. Short-term benefits include conservation of important water supplies, enhanced habitat availability to both the springs ecosystem and to surrounding habitats, and the preservation of sensitive species. Long-term benefits of springs rehabilitation include increased sustainability of resource management, better economic and water supplies security, and more efficient adaptation to climate change.

Fig. 1.17: Pakoon Springs, Mojave Desert, Arizona: (left) Prior to 2007 restoration, (right) visible progress in 2011. Photos courtesy of Grand Canyon Wildlands Council © 2015.


ESPIL
ASPEN
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Chapter 2
Inventory and Assessment
of Springs Ecosystems

Before beginning the rehabilitation of a springs ecosystem it is important to understand its ecological condition and its relation to other springs and management issues in the land unit of concern. Inventory is a fundamental element of ecosystem stewardship, providing essential data on the distribution and status of resources, processes, values, and aquatic, wetland, riparian, and upland linkages (Busch and Trexler 2002). Systematic inventory precedes assessment, planning, action implementation, and monitoring in a structured resource management strategy. In this chapter we offer an efficient, comprehensive inventory and assessment approach for springs, and a secure, user-friendly information management system for data archival, restoration planning, implementation, monitoring, and reporting.

SSI synthesized inventory and assessment information needs and perspectives from the literature and discussions with many private, Tribal, and agency staff over the past 15 years to refine sampling protocols for the many resource variables of potential interest to springs stewards. These references included methods developed by the Department of Defense, the U.S. Forest Service (2012), the U.S. National Park Service (Springer et al. 2006), the U.S. Bureau of Land Management (1991, 1998; Sada and Pohlmann 2006), several southwestern USA Native American Tribes, U.S. academic institutions (e.g., Paffett et al. 2014), and the Australian government (Eamus et al. 2014). These sources revealed a suite of variables of primary interest to springs stewards: geomorphology; aquifer mechanics and sustainability; flow and water quality; aquatic and wetland vegetation; aquatic and wetland faunae; fish; other vertebrates; cultural elements, including ecosystem goods and services; and the administrative context of springs stewardship, including water rights and other regulatory issues. Information collected through systematic inventory was needed not only for the project at hand, but also for comparing site change over time, comparing and prioritizing management at other springs in the region, and providing a relevant monitoring baseline.

SSI developed, tested, and refined its protocols and the Springs Online database by inventorying more than 1,000 springs across North America, from Alberta (Canada) to Mexico.

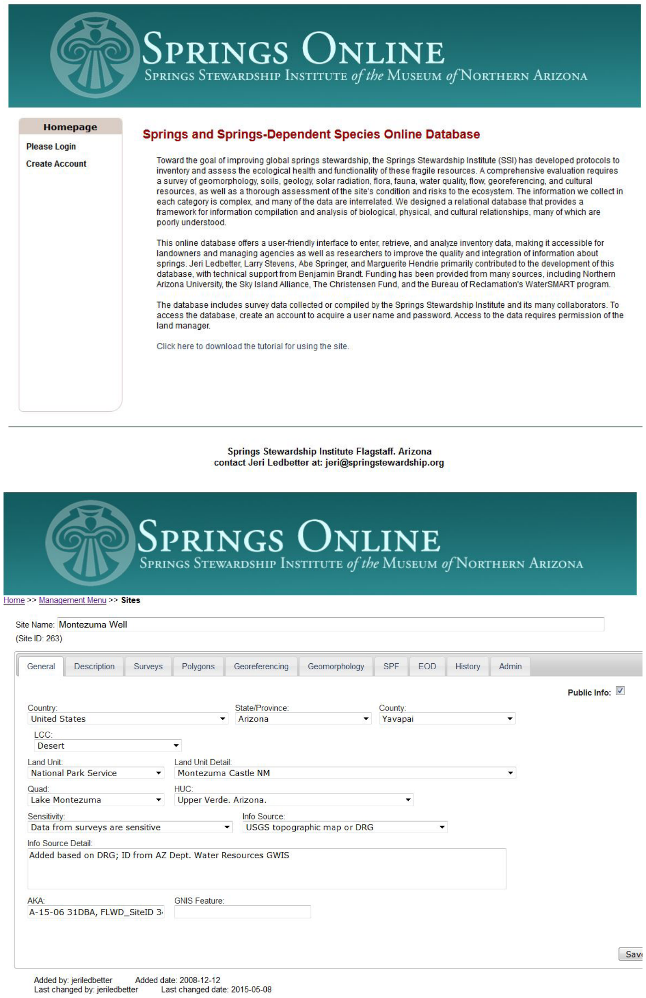


Fig. 2.01: Springs Online at http://springsdata.org/. SSI has developed and maintains this secure, user-friendly online database that allows land managers, researchers, Tribes, and non-profit organizations to enter, analyze, and report upon springs related data. Any user may set up a password-protected account, but permissions are required to access non-public data. Land managers have full control over who may access or edit survey data. As of December 2015, the database contained information about over 90,000 springs and supported over 300 user accounts. A training tutorial is available at: http://springstewardshipinstitute.org/database-manual-1/

Here we present SSI's integrated springs inventory and assessment protocols and information management system for the diverse array of springs ecosystem variables in an efficient, effective stewardship program. SSI's Springs Online database (http://springsdata.org/, Fig. 2.01) is a freely available relational database that readily incorporates inventory information and, in concert with expert opinion of the springs inventory team, applies that information towards ecosystem assessment, to simplify stewardship planning, implementation, and monitoring.

In this chapter we describe background information needed to initiate a springs inventory project or program. We emphasize the initial need for detailed mapping of springs, a topic that is particularly important in large landscapes where springs distribution often is imperfectly known and where geographic analyses are needed for inventory logistical planning. We then outline inventory protocols of interest to springs stewards, and how that information is best used for ecosystems assessment and prioritization. These protocols provide stewards with comprehensive, efficiently collected and databased, reliable, and readily understood information on springs ecosystem components, processes, threats, and stewardship options. The protocols recommended here can be used at an individual springs ecosystem, or for an inventory across a broad landscape, and many of the techniques are appropriate for monitoring as well to evaluate the effectiveness of the stewardship action or to quantify regional ecosystem changes over time. Thus, Level 2 inventory and assessment protocols can be used to facilitate discussion and stewardship of aquifers and springs that cross political boundaries. In subsequent chapters, we describe how information entered into the Springs Online database can be used in restoration planning, implementation, and monitoring.

Inventory Protocols

Seeps, Springs and Wetlands

Much confusion has arisen over the relationship between seeps, springs and wetlands, retarding recognition of springs as important ecosystems and jurisdictional habitats in the United States. All springs are groundwater-dependent ecosystems (GDEs), but not all wetlands are GDEs. Seeps are simply small, sometimes ephemeral springs, often with diffuse, difficult-to-measure flow. US Environmental Protection Agency wetland delineation concepts and techniques are not universally applicable to springs, particularly smaller springs, naturally ephemeral springs, hot springs and geysers, or hanging gardens and other springs in bedrock-dominated landscapes (hygropetric springs). Although most springs are small, their remarkably high productivity, support of high concentrations of species, and economic value underscore their important function and role throughout Arizona.

Springs Inventory and Assessment	
Level 1	General Reconaissance - A rapid survey of springs within a landscape by 1-2 staff for the purpose of georeferencing, clarifying access, and determining equipment needs.
Level 2	SIP and SEAP - A detailed survey of a springs ecosystem to describe baseline physical and biological data, human impacts, and administrative context variables. (Table 2.02)
Level 3	Monitoring and Research - monitoring of springs selected for long-term research or restoration. Includes variables measured in multiple Level II inventories, as well as other specific variables relevant to restoration project goals. (Chapter 6)

Table 2.01: Three levels of inventory from protocols developed by Stevens et al. (2011).

Three Levels of Inventory

In this section we describe springs inventory protocols for cost-effective, comprehensive springs ecosystem inventory and monitoring. We define three levels of inventory (Table 2.01):

Level 1 inventory involves a rapid reconnaissance survey of springs within a landscape or land management unit, including brief (10-20 minutes per site) visits by 1-2 staff for the purpose of georeferencing, clarifying access, and determining sampling equipment needs.

Level 2 inventory is a detailed survey of a springs ecosystem by an expert team that typically spends one to three hours at a springs, describing baseline physical, biological, human impact, and administrative context variables (Table 2.01, field forms in Appendix C).

Level 3 inventory involves monitoring of springs selected for long-term research or restoration, and includes variables measured in the Level 2 inventory, as well as other specific variables relevant to the restoration project goals (Chapter 6).

As mentioned above, Level 2 inventory data gathered from laboratory (mapping) and field site visits are compiled into the Springs Online database (Fig. 2.01) and used to inform assessment of the ecological integrity of the springs ecosystem through SSI's springs ecosystem assessment protocol (SEAP). A SEAP report provides springs stewards with clear interpretation of springs ecological conditions and risks from the manager's perspective. Further clarification of the relationship between this prioritization and specific management needs requires additional discussion with the stewards (e.g., Paffett 2014).

The measurements and estimates, data entry, quality control, data archives, and interpretation of the above inventory variables are described on the SSI website (springstewardshipinstitute.org). SSI and SIA offer springs inventory and assessment guidance and trainings through in-person, online and webinar sessions.

Nogales Spring, Arizona—a limnocrene (pool forming) spring. SIA photo.

Table 2.02: List and description of primary variables measured or observed during a Level 2 springs ecosystem inventory, and information sources: F – field site visit, L – laboratory analyses, O – office. See key in Level 2 field forms. (Continued on following pages).

Variable Category	Variables	Description	Data Source
Site Data	Spring Name, country, state or province, county or municipality, 8-digit Hydrologic Unit Code (HUC), Landscape Conservation Cooperative (LCC), Other names, Information source, Public (Y/N), Sensitivity.	General Information about the site and the location. Many of these fields are most easily populated through GIS during the Level 1 process, and/or refined after the initial survey. The information source, public checkbox, and sensitivity level indicates the source of location data, and what users should have access to it.	O
	Site ID	The Springs Online database automatically populates this value. Additional fields are provided for the individual land unit's site ID.	O
	Land Unit and Land Unit Detail	Land owner (NPS, USFS, private, etc.), and unit (eg. Saguaro National Park, North Kaibab Ranger District, etc.)	O
	Georeferencing: Information Source, Coordinates, Device, Latitude & Longitude, Elevation (m), Accuracy (EPE, (m), GPS/GIS Comments	Information Source (map, GPS, etc), Datum (should be converted to WGS84 for Springs Online database). Coordinates may be UTMs or Latitude/Longitude, preferably in Decimal Degrees.	F
	Access Directions	This information is most important for sites that are difficult to reach, such as those requiring a long hike or a climb, crossing private posted land, etc. Any crew safety concerns should be recorded here, as well as notes about culturally sensitive sites.	F
	Site Description	This free text field should describe the long-term characteristics and setting of the spring, including the extent and forms of human alteration. It should not include temporal information about its condition.	F
	Solar Radiation Budget	Sunrise and sunset using a solar pathfinder to calculate total % seasonal and annual solar flux.	F
	Springs Type	Springs type(s)	F
	Polygon code and description	Identify discrete geomorphic microhabitats with codes A, B, C, D...	F

Variable Category	Variables	Descrption	Data Source
Survey Data	Date, Start Time, End Time, Surveyor's Names, Project Name, and Survey Protocol.	The date is a required field. The surveyors names, beginning and ending times indicate the thoroughness of the survey. The Project Name is required, allowing a set of surveys to be analyzed. The protocol is also required, identifying what protocols were used (eg. USFS GDE Level I, PFC, etc.).	F
	Polygon area (m^2); Surface Type and Subtype; Slope Variability (low, medium, high); Aspect (MN or TN); Soil Moisture; Water Depth; % Open Water; % composition by surface substrate particle size (1 to 8) plus Organic Soils and Other (typically anthropogenic); % cover of Precipitate, Litter, Wood; Average Litter Depth (cm).	Describe the characteristics of each microhabitat (polygon). Area may be calculated from the sketchmap for small sites, or by aerial imagery in GIS or walking the perimeter with a GPS for large, flat sites. Microhabitats are assigned to a site during the first survey, but may be adjusted as necessary for subsequent surveys should the geomorphology change.	F
	Site Condition	This is a free text field to describe the condition of the site at the time of the survey. For example, this should include human impacts, indications of fire or flooding, extent of grazing or browsing damage, abundance of wildlife, condition of vegetation, etc.	F
	Photographs	Include the photo number and description of photographs taken, as well as which camera was used. Indicate photo sites on the sketchmap.	F
	Sketchmap	Hand drawn map, aerial photograph, or digitized map with scale, orientation, date, observers, landmarks, georeferencing points, photo points. Indicate location of the sketchmap (attached, computer, etc).	F
Biotic Inventory	Aquatic, wetland, and terrestrial plant species inventory	List of species detected, noting endemic and nonnative taxa; visual estimation of % cover in each polygon by stratum: ground (0-2 m graminoid/herb/non-woody deciduous) shrub (0-4 m woody perennial) mid-canopy (4-10 m woody perennial) tall canopy (>10 m woody perennial) non-vascular basal aquatic	F/L
	Aquatic, wetland, and terrestrial invertebrate species inventory	List of species detected, noting endemic and nonnative taxa, data collection type (spot or quantitative), species enumeration, substrate, depth, velocity notes for benthic sampling.	F/L
	Aquatic, wetland, and terrestrial vertebrate species inventory	List of species detected, noting endemic and nonnative taxa, and detection method (sign, observation, call, etc)	F/L

Variable Category	Variable	Description	Data Source
Geomorphology	Emergence environment	Cave, subaqueous, subaerial, other.	F
	Flow force mechanism	Gravity, thermal pressure, etc.	F
	Hydrostratigraphic unit: geologic layer of aquifer, rock type	Describe parent rock and rock type.	F
	Channel dynamics	Surface vs. springflow dominance.	F
	Source geology and flow subtype	Springs emergence: contact, fracture, seepage, tubular.	F
	Sphere of discharge and secondary sphere by polygon	Describe the springs type and subtype for each microhabitat: Cave, limnocrene, rheocrene, mound-form, helocrene, hillslope spring, gushette, hanging garden, geyser, fountain, hypocrene, paleocrene.	F
Flow	Flow consistency	Describe perenniality of flow from long-term records or history, geologic features, dendrochronology, presence of aquatic organisms.	F/O
	Flow measurement technique(s), location, and calculated mean rate (L/sec)	Record replicated flow measurements, describe the technique used, and note measurement location on field sheet and sketch map.	F
Water Quality	Instrument used and date last calibrated. Field water quality parameters: air and water temperature at the source; pH; specific conductance @25µm/cm; concentrations of dissolved oxygen, and total alkalinity	Instrument should be calibrated at least daily for accuracy; maintain a calibration log. Correct electrical conductivity for temperature. Measure water chemistry as close to the source as possible. See Chapter 6 for protocols.	F
	Laboratory WQ: Concentrations of base cations and anions, total dissolved solids, H and O stable isotopes, and other variables of interest.	Collect and filter water quality samples as close to the source as possible in acid-washed container. Refrigerate, and analyze as soon as possible. See Chapter 6 for protocols.	L

Variable Category	Variable	Descrption	Data Source
Cultural resources	Contemporary cultural resources (TCP, ethnobiology, etc.)	Interviews with tribal elders, botanical inventory, site visits with tribes, literature review	O, F
	Historical resources, histories	Historical surveys, literature review, interviews with elders	O, F

Preparing for Inventory

Defining Stewardship Goals

Well-defined goals, objectives, and questions help focus limited funding on the issues of most importance to the manager, and are the most important start-up tasks for springs stewards.

The first order of business is to understand springs distribution; this Level 1 task routinely is underestimated by agency and other large-landscape springs stewards. It has been a common experience in our work with dozens of large landscape managers that detailed knowledge of springs distribution and types within large landscapes is poorly known (e.g., Springer et al. 2014). Private landowners often understand the distribution of springs on their land better than do agency staff. However, at coarse spatial scales, global and national mapping of springs is inadequate, and few states have accurate maps of springs. Nonetheless, on the scale of aquifers, georeferencing information is critically important for understanding: 1) the extent of information available on springs; 2) the distribution of springs types in the landscape; and 3) site selection process for inventorying critical springs in the region. Level 1 inventory requires trust and collaboration among neighbors and governing officials.

Another common stewardship question in large landscapes with many springs is, "What is the ecological condition and sustainability of our springs?" This question can only be answered accurately by inventorying a randomly selected set of springs. However, such site selection is blind to the issues of logistical cost and crew safety, so some sideboards are placed on sampling. Nonetheless, such data provide powerful answers to this particular stewardship question.

Individual stewards also often have questions about specific, high priority springs because such springs are likely to be the largest, most highly valued water sources in the project area. Although dozens or hundreds of other springs may exist in the landscape, the steward may only seek information about the condition of these target springs. Use of the SSI Level 2 and 3 protocols presented below are usually adequate for such studies.

Background Information Needs

Springs stewards need background information about the region, from those managing a single springs ecosystem for domestic water supplies to those managing large landscapes with hundreds or thousands of springs. Relevant information includes: 1) the groundwater hydrogeology of the regional aquifer(s), including climate influences and change; 2) the array of springs types in the region (how rare is the springs type to be rehabilitated?); 3) regional ecology, biodiversity, and distribution, particularly of sensitive species and habitats; 4) sociocultural prehistory and history; and 5) land and resource management policies. Such information provides critical basic understanding of individual springs or springs within the region, and serves as baseline reference documentation. In addition, such information may help refine stewardship goals. Much information may be available from the literature or through discussion with experts; nonetheless, it is best compiled into a concise, well-referenced, archived report so that present and future stewards have a clear understanding of the rationale for, and history of management decisions.

Groundwater Modeling

Among the most informative studies available for planning springs restoration is groundwater modeling, which summarizes existing data and provides an essential tool for planning and successful accomplishing springs rehabilitation. High quality models address the risk of dewatering, changes in water quality, the influences on the springs from the surrounding landscape, and climate change risks. Groundwater modeling is available for active management areas in Arizona and in some large regions of the state (e.g., USGS 2012). But often no groundwater model may be available for specific rural aquifers and the long-term sustainability of many aquifers are left in question. If at all possible, securing or developing a groundwater model for the aquifer from which the springs emerge is useful for understanding springs distribution, flowpath duration, and water quality prior to undertaking springs rehabilitation.

Cultural Values

Although much emphasis has been placed on the biological values of springs, few regional inventories of the indigenous cultural attributes of springs exist, despite widespread regard for springs as culturally and spiritually important landforms (e.g., Nabhan 2008; Rea 2008; Phillips et al. 2009). Neither have the socio-economics of Arizona springs been explored.

Preparing for Field Work

Site Selection

Springs inventory of large or complex landscapes requires several levels of logistics planning, and that planning should be designed to address the questions of primary interest to the steward(s). In large landscapes, the questions “What is the distribution of springs types?” and “What is the condition of our springs?” require statistically rigorous sampling that is not biased by undue attention to individual springs or springs types.

Springs often occur in clusters that are typologically and geochemically similar, and often are subject to similar stewardship strategies. Therefore, we find it most useful to use the Level 1 inventory to conduct a statistical cluster analysis based on latitude, longitude, and elevation. We then randomly select clusters, and randomly select one to several springs per cluster. This stratified random sampling approach allows us to select an unbiased suite of springs for Level 2 inventory. The sample size should be sufficiently large (30-50 springs at least) to allow for detection of rare springs types, although there is no guarantee that such an effort will detect the rarest types of springs. However, if springs types are known in the Level 1 survey, it is also feasible to further randomly stratify the sample by springs type to ensure inventory of all types within the landscape.

Timing Site Visits

In Arizona, springs base flow and water quality are most unambiguously measured during mid-winter, when plant transpiration losses are low. However, the middle of the temperate growing season is likely to be most revealing for biological variables. While a single site visit is highly informative, Grand Canyon Wildlands Council (2004) reported that three site visits in different seasons were needed to detect >95 percent of plant species at a large site, while six or more site visits (including nocturnal sampling) were needed to detect most of the aquatic and wetland invertebrate taxa at large springs. Inventories for fish and amphibians also require several visits, while detection of other wetland, riparian, and terrestrial vertebrates may require numerous visits in a longer-term monitoring context.

Springs ecosystems change seasonally in relation to climate and at random, and every site visit or

Fig. 2.02: Plant identification will be most accurate if surveys are timed in the middle of the growing season. SIA photo.

inventory is a snapshot in time (Fig. 1.05). Understanding the range of natural variation at springs is key to improving stewardship, and therefore consistent, thorough inventory techniques expand our appreciation of the dynamism of these ecosystems.

Trip Logistics Planning

Following site selection, it is important to develop a route for the inventory team to access groups of springs that minimizes travel distance and time, and also indicates natural barriers that may delay or prevent access (e.g., river crossings, escarpments, etc.). For larger projects, it may be helpful to complete a route analysis in GIS.

Permits

Prior to data collection, state, federal, or Tribal permits often are required from the entity responsible for land stewardship. Permits may be required for each land unit visited if a project extends across political jurisdictions. Such individual land unit permitting may substantially delay inventory, assessment, and rehabilitation work. If specimens are to be collected during inventory, appropriate repositories should be used or established, and voucher specimens should be collected, prepared, and stored in professionally curated collections for further research, monitoring, or potential litigation.

Fig. 2.03: Flow measurements will be affected by plant transpiration during the growing season. SIA photo.

Equipment List

The equipment we have found most useful for Level 2 surveys are listed in Appendix C. Given that some potentially useful equipment, such as a cutthroat flume are heavy devices to transport, information from the Level 1 survey on which flow measurement devices are needed is useful.

Safety

Safety is first in importance for the field team, and is the primary responsibility of the crew leader. Vehicular safety, communications, first aid, instruction in the use and care of special equipment, and final command over the safety of access are concerns for each member of the crew. The crew leader is ultimately responsible for compilation and security of the information collected, and the safe return of the crew and the equipment. In remote areas, the crew should always carry sufficient supplies of water, food, flashlights, shovels, extra spare tires, and first aid and emergency supplies to deal with accidents and unexpected circumstances, such as rapid changes in weather. We GPS our vehicles prior to starting on remote field inventories, to ensure ease of relocating them, particularly at night.

Ensuring the safety of the springs under study is also the responsibility of the inventory team. The crew should make sure that no weed propagules are transported onto the site (e.g., on nets or clothing), and that the site is left in as close to its original condition as possible after the inventory

Fig. 2.04: Some springs are particularly challenging to access. Snowslide Spring on the San Francisco Peaks, Arizona. Photo courtesy of Don Keller.

in completed. Crew boots and all nets and other equipment exposed to the site should be sterilized with a 1% solution of sodium hypochlorite (household bleach is about 4% sodium hypochlorite) or other appropriate disinfectants prior to visiting the next site. However, high concentrations of sterilization compounds have deleterious impacts on amphibians and likely other springs-dependent species (e.g., Hangartner and Laurila 2012), and therefore, a follow-up rinsing with sterile water is recommended.

Contingency Planning

It is nearly axiomatic that the more expensive field electronic equipment is, the more likely it will fail in the field. Therefore, it is important to have backup systems or a strategy to cope with equipment failure. Also it is common to encounter unmapped springs during the course of searches for reported springs, and the crew should have a plan for such encounters. The choices in such circumstances range from georeferencing and photography in a Level 1 site verification of unreported springs, to conducting a full Level 2 survey of all unreported springs. Such decisions should be clearly defined prior to sending out field crews to conduct Level 2 inventories.

Inventories

Level 1 Inventory

Level 1 inventory should begin as an office exercise to find and database all known information on the distribution and characteristics of springs within the project area. Sources of information include topographic maps, prior hydrologic resource and modeling surveys and studies, interviews with knowledgeable individuals, remote sensing analyses. No single source of information is likely to be complete, and mapping precision and accuracy can be highly variable. GIS datasets are inconsistent with location and spring names (Fig. 2.05). Therefore, the locations and names of individual springs may be uncertain and should be treated as such until verified in the field. In the SSI database, Level 1 springs data are coded in an Inventory Status field as Unverified, Verified, or No Spring, with subcategories for each (Fig. 2.06). This information can be mapped in GIS throughout a project to monitor progress (Fig. 2.07).

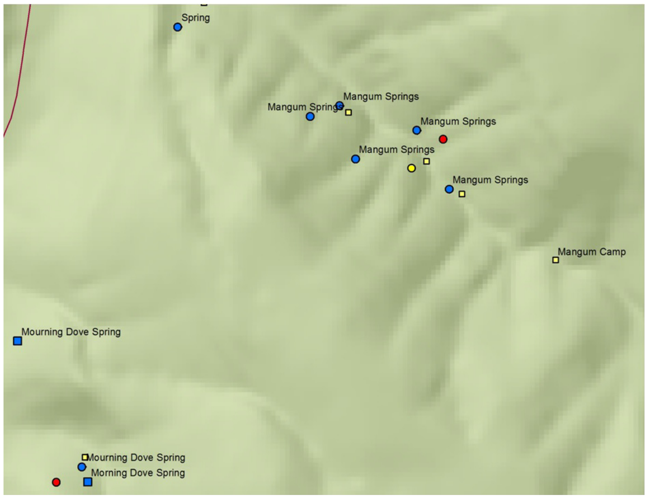


Fig. 2.05: Example of the results of combining several datasets for springs on the North Rim of Grand Canyon. Mourning Dove spring is mapped in four different locations, misspelled in one dataset, and unnamed in two. Clusters of springs, such as in Mangum Canyon increase the difficulty of reconciling datasets.

Unverified

- Potential spring, not verified
- Spring reported dry or ephemeral, not verified
- Spring Reported, not verified

Verified

- Verified, but dry or ephemeral
- Spring outflow observed, source location unknown
- Spring verified and georeferenced

No Spring

- No evidence found during intensive search
- Paleospring
- Re-emergence or outflow from upstream source
- Site verified, but not from groundwater source

Fig. 2.06: Categories and subcategories for unserveyed springs in the Springs Online database.

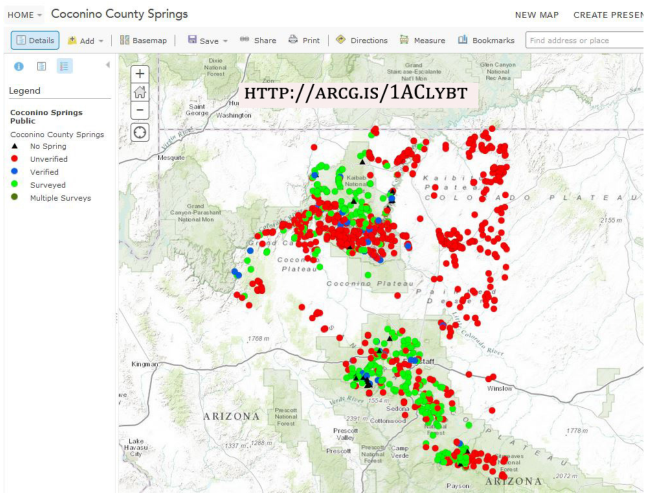


Fig. 2.07: SSI publishes mapping services using SSI's springs geodatabase, populated from Springs Online, to map inventory status of springs within a land unit.

Fig. 2.08: Surveyors record the sunrise and sunset at the source of a spring using a Solar Pathfinder.

Level 2 Inventory

Overview

Level 2 surveys are designed to be rapid, comprehensive measurements, observations, and assessments of springs ecosystems, data that can be used to assess the site's ecological condition and risks from human impacts. These observations are conveniently recorded on SSI's Level 2 inventory datasheets and are easily entered into the SSI Springs Online database.

Site Identity and Geography (SSI Datasheet pages 1 - 2)

In the first section of page 1 of SSI field sheets, surveyors record general location information about the site—the spring name, state, county, land ownership, site description, and coordinates. Surveyors should also enter access directions, noting any challenges, such as a difficult climb, crossing private land, etc. Much of this can be completed prior to field work, but it is usually necessary to adjust the GPS coordinates.

The next section focuses on the survey—the date, starting and ending time, surveyors' names, and site condition at the time of the visit.

The solar radiation budget is measured with a Solar Pathfinder that provides mean monthly time of sunrise and sunset (Fig. 2.08).

The crew jointly discusses the array of microhabitats, and on page 1 describes each microhabitat type, area, aspect, slope angle, amount and depth of water or soil moisture, visually-estimated percent grain size (clay, silt, sand, pea gravel, etc. up to bedrock, and soil), and percent cover of precipitate, wood, and cover and depth of litter. Variable names and reminders for data recording are listed on page 2 of the SSI Datasheet.

At the bottom of that page, the team geographer records photographs taken of the site, along with their file numbers, and whose camera was used.

One surveyor draws a map to scale, depicting the surface area of each microhabitat on the site. The sketchmap should be properly labeled as to site name, land ownership, inventory team members, and must contain a scale bar and north arrow. The springs source(s) and locations of water quality, flow, and SPF measurements, as well as distinctive landscape features are included on the sketchmap. For large, flat sites with few microhabitats it is sometimes easier and more accurate to create a sketchmap in GIS using aerial imagery (Fig 2.09).

Level 2 Biological Variables (SSI Datasheet pages 3-6)

Vertebrate Inventory (SSI Field Sheet Page 3)

Biological variables are often particularly important components of springs ecosystem inventory, assessment, and monitoring. The team biologists record evidence of vertebrates on SSI data sheet page 3. The biologists should be the first to approach the site to detect wildlife because most wildlife will quickly abandon the site, and the sur-

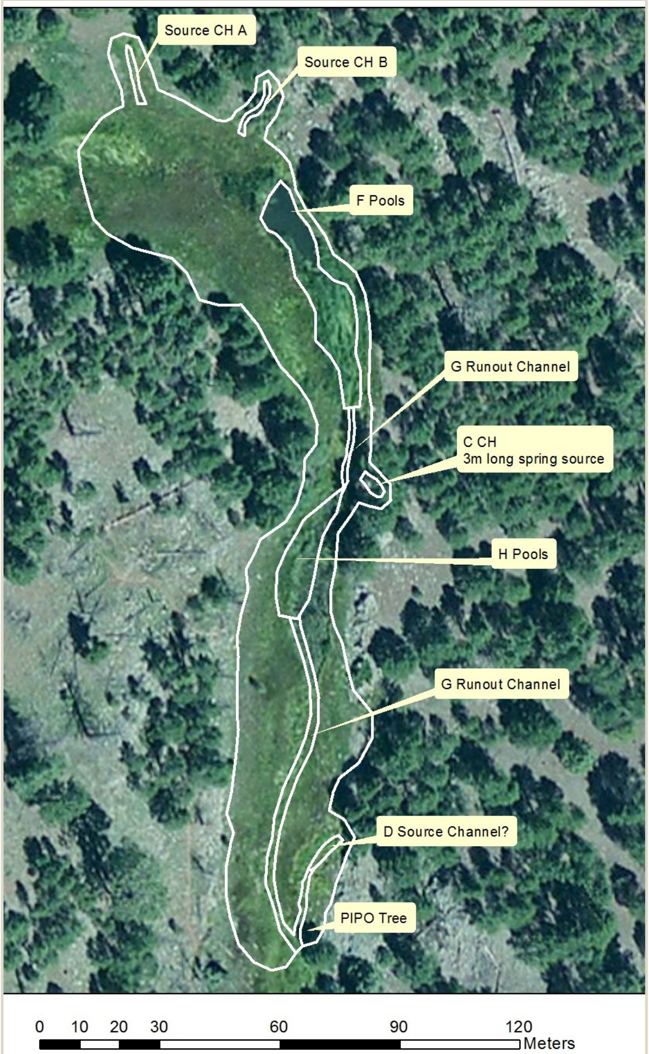


Fig. 2.09: This sketchmap was created by walking the perimeter of a site with a GPS, importing it into GIS, and using aerial imagery.

veyors are likely to obliterate sign and tracks. (Fig. 2.10). The crew should take note of birds and wildlife that approach the site during the survey. However, there is no expectation that a Level 2 survey will provide a complete list of the vertebrates using the site. Developing such a list requires a Level 3 long-term monitoring effort, the installation of motion detecting cameras, systematic bird and small mammal surveys, and other longer-term data collection.

Invertebrate Inventory (Field Sheet Page 4)

Invertebrates are often excellent indicators of springs ecological integrity. The biologist should intensively explore the site for aquatic and wetland macroinvertebrates. This opportunistic (spot) sampling may reveal rare species that cannot be practically sampled quantitatively. Where

Fig. 2.10: 2 inch diameter bobcat print found at a spring in Northern Arizona.

sufficient flow exists, at least 3 quantitative benthic samples should be collected. In such settings, a fine-mesh Surber or Hess (basket) sampler, kick-net, or D-net can be randomly placed with the current running through the net. A uniform area of stream floor immediately upstream from the net should be vigorously disturbed for 1 minute to sweep aquatic invertebrates into the net. The biological sample can be crudely counted in the field, or returned to the laboratory in 70% or stronger EtOH for detailed enumeration, depending on the project needs. The depth, velocity, and visually estimated substrate particle distribution should be recorded for each replication, and sampling should take place in an upstream direction. At low flow springs, only simple presence/absence detection of aquatic and wetland invertebrates may be possible. Specimens should be prepared and curated according to standard museum protocols.

Fig. 2.11: SSI staff sampling for aquatic invertebrates at Deer Lake, Kaibab National Forest. Photo by Molly Joyce.

Botanical Inventory (SSI Field Sheet Page 5-6)

Vegetation composition and structure are quantified by visually estimating the percent cover of each plant species detected in seven cover strata, including cover of: aquatic, non-vascular (e.g., moss, liverwort), basal (live or dead tree trunks emerging from the ground), ground (deciduous herbaceous or graminoid), shrub (0-4 m woody perennial), middle canopy (4-10 m woody), and tall canopy layers (>10 m woody; Stevens et al. 2011). The botanist walks through the site, develops a plant species list, and then visually estimates cover in each of the above strata for each species in each microhabitat polygon. A botanical assistant is helpful in the initial plant search and also as a second opinion for cover estimates. Specimens or parts of specimens of unidentified plant species are collected and transported to the laboratory for identification. Plant species taxonomy and native vs. introduced status are identified in the database in accordance with the USDA-PLANTS database (2013). Specimens of interest should be prepared and curated according to standard herbarium protocols (Fig. 2.12).

From these data, we can calculate the percent cover of: native versus nonnative vegetation, wetland versus non-wetland vegetation, and plant species density (total species richness divided by the area). We can analyze vegetation composition using basic and multivariate techniques, and describe the vegetation architecture at the site using the percent cover by stratum data.

Fig. 2.12: Collecting unknown plants for identification and curation. SIA photo.

Fig. 2.13: There are many ways to measure flow during a Level 2 inventory. SIA photo.

Hydrological Variables (SSI Field Sheet Page 7-8)

Categories of geohydrological field variables of interest at springs include a physical description, flow, and water chemistry.

A physical description of the site includes the source geomorphology, spring type, bedrock and structural geology, flow forcing mechanism, and perenniality.

Flow is of primary interest to stewards, and its measurement is site- and time-specific. There are many ways to measure flow; SSI protocols list 16 methods based on site conditions and flow magnitude (Fig. 2.13). We provide more detail in Chapter 6 and Appendix B. For small springs, timed flow capture is often the most reliable and accurate approach. Surveyors should measure and photograph flow where discharge is greatest, rather than at the source. Springs often have multiple sources that converge before sinking back underground.

Discharge measurement is not possible at all springs types. For example, helocrene springs can have diffuse flow and may require a different flow measurement approach than do springs types with

Fig. 2.14: Springs often have a long history of human manipulation.

focused flow (i.e., hillslope, hanging gardens, or rheocrene springs). In the case of helocrenes, wall seeps, and other diffuse flow emergences, measuring wetted area and piezometric well depth-to-water-table measurements may be the primary means of evaluating or monitoring flow.

The team hydrogeologist measures field water quality variables at the first exposure of water, as close to the source as possible. Field variables include water temperature, pH, specific conductance (electrical conductance adjusted for temperature), dissolved oxygen concentration, and total alkalinity, and total dissolved solids (TDS). The hydrogeologist calibrates water quality meters daily during inventories, and maintains a calibration log.

Laboratory analyses (e.g., nutrients, trace ions including heavy metals, stable isotopes) can be made on properly collected and filtered water samples; however, these variables can be costly to analyze, and project budget considerations need to be evaluated carefully. Such water quality variables should be analyzed at a state- or federally-certified laboratory.

It is important to record the associated metadata and quality control information. Surveyors can attach such documents to the survey at Springs Online.

Human Impacts

The inventory team should note all signs of human activity, with the understanding that most of the prehistory and history of the site may not be visible. Often, the presence of a single fence stake, a fragment of concrete, or an old pipe may be the only evidence of prior human use. The cultural expert on the crew should have a good understanding of land use history of the area, and that of the individual springs ecosystem being inventoried. Surveyors can summarize comments about human impacts in the Site Condition field on page one of the field sheets, as well as noting specific impacts on appropriate pages. Human impacts are reviewed during the assessment process (See below).

Information Management

The above inventory protocols were developed on the assumption that the springs steward(s) use and maintain a long-term information management program for springs rehabilitation projects. In the case of large landscape management units (National Parks, National Forests, Tribal reservations, etc.), such information management systems need to be relatable to the steward's goals as well as their geographic information system (GIS) program, and stewards are likely to need data archival, site photography, appropriate specimen curation capacity, and clearly-defined metadata and reporting standards. The springs information management system and its metadata should be easily accessed, should be entirely secure to protect sensitive data, and should readily allow for new analyses. Few such data management systems presently exist for springs ecosystems. Therefore, what little information exists tends to be fragmented, and largely unavailable to land managers, researchers, and conservation organizations.

SSI developed Springs Online (http://springsdata.org) to fill this information gap, providing a user-friendly interface for data entry, and analysis. The fields in the database have dropdown boxes and are aligned with the field sheets to ease the data entry process. A typical Level 2 survey can be entered in less than two hours.

This technology is freely available to all Arizona springs stewards who sign up for an account. With interest, examination of the tutorial, or online

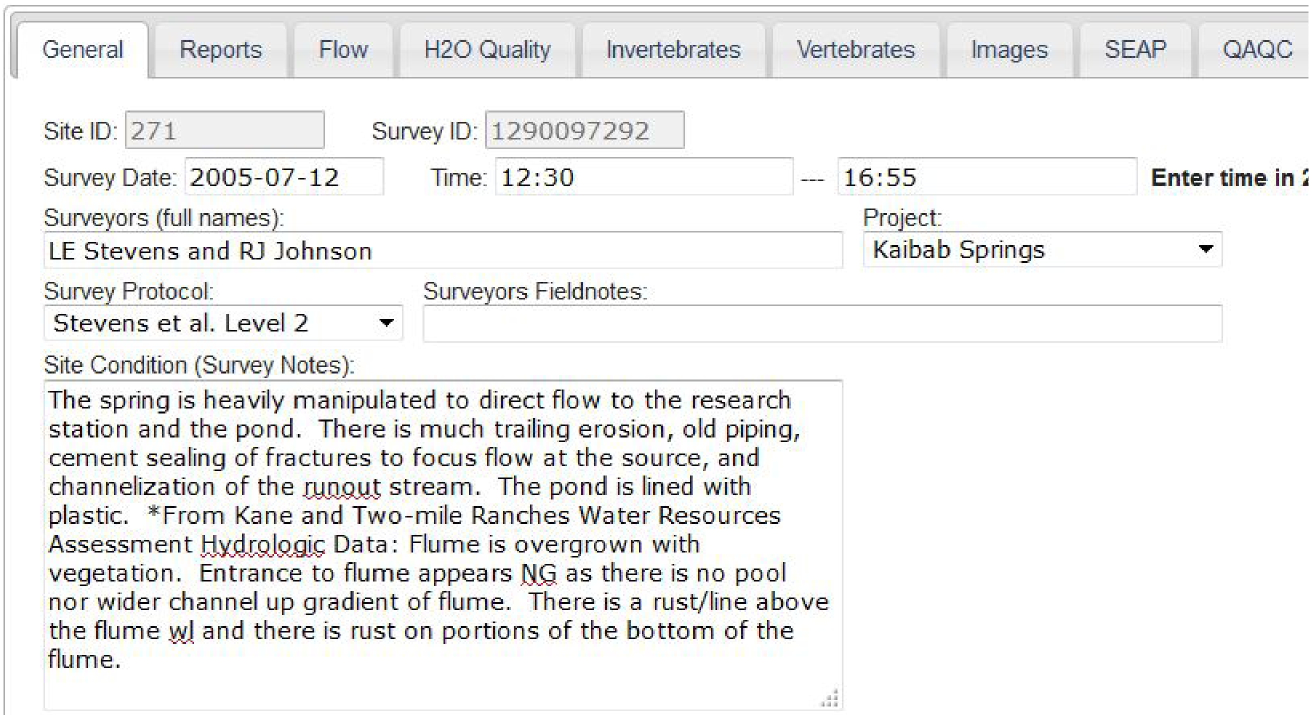


Fig. 2.14: Interface of Springs Online, a relational database available to land managers, researchers, and conservation organizations.

training, virtually any English-speaking individual can use this electronic portal to compile, archive, monitor, and report upon the condition of springs. Easy retrieval of information from the SSI database provides long-term evaluation of change and response to management activities. The user manual is available at http://springstewardshipinstitute.org/database-manual-1.

Springs Ecosystem Assessment (SEAP)

Overview

The U.S. Environmental Protection Agency, Army Corps of Engineers, and state water quality offices protect ground and surface water quality, wetland ecosystem health, and relevant ecosystem, sociocultural resources and impacts, and other natural and social aquatic and wetland ecosystem functions as needed (e.g., Cowardin et al. 1979; National Research Council 1992, 1994; Federal Geographic Data Committee 2013). Springs ecosystem inventory and assessment protocols and recommendations should be consistent with those and other federal land and resource management legislation (e.g., the Antiquities Act of 1906, the National Park Service Organic Act of 1916; the multiple use mandates of the U.S. National Forest Service and the Bureau of Land Management, the Clean Water Act of 1973, and the Endangered Species Act of 1973, as amended, as well as state and local policies).

Wetlands delineation and management fall under the jurisdiction of the United States (U.S. Army Corps of Engineers 1987), and consume much technical and regulatory attention. However, discussion of springs is ambiguously included in federal wetlands policy, as defined by the U.S. Fish and Wildlife Service (Cowardin et al. 1979) and the Federal Geographic Data Committee (FGDC 2013). Recent attention to isolated waters of the United States places springs on a list of aquatic re-

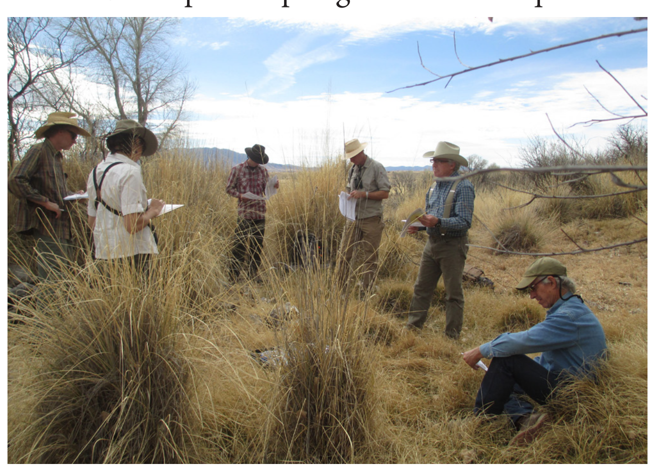


Fig. 2.15: Meeting with landowners to discuss springs administrative context, values, and cultural history. SIA photo.

Fig. 2.16: Montezuma Well, a limnocrene pool in a collapsed carbonate mound located in Montezuma Castle National Monument in central Arizona. The spring supports high concentrations of endemic species due to its unique water chemistry. Molly Joyce photo © 2015.

sources potentially falling under the managerial oversight of the Environmental Protection Agency (EPA). Although the EPA may regard springs as jurisdictional waters of the United States, such governance still appears to be in flux. Consideration of flow contributions from springs to wetlands also may initiate additional discussion of the role of springs in wetland habitat management.

The National Wetland Inventory (NWI 2015) defines a wetland based on the occurrence of at least one of the three wetland characteristics (hydric soils, wetlands vegetation, and a hydrologic regime with at least seasonal saturation). However, the Federal Geographic Data Committee (FGDC; 2013:64) wetlands identification key inadequately recognizes most springs types as wetlands. Rheocrene and hanging gardens key out in that document as riverine wetlands, while most other springs types key out as palustrine (marshy) wetlands - including helocrene, hypocrene, gushet, shallow-water hanging gardens and carbonate or ice mound, fountain, geyser, exposure, hillslope, and cave springs. Deep water limnocrenes key out as lacustrine (lakes); and paleosprings and subaqueous springs do not fit at all in the FGDC key. Therefore, jurisdictional progress will require improvement of governmental understanding of the variability in springs types (e.g., Springer and Stevens 2008; Figs. 1.06 and 1.07).

SEAP Analysis

SSI's springs ecosystem assessment protocol (SEAP) is based on a Level 2 inventory to evaluate a site's ecological integrity and risk level. The SEAP is a process of evaluating and comparing inventory data within and among sites, as well as assessing other external information to generate management guidance to springs stewards on the resource conditions and risks among six categories of variables. Such an overall assessment of springs ecological integrity, human impacts, and management context is often needed to organize and prioritize stewardship planning, implementation, and monitoring for a specific springs, or across an entire landscape. Ecological assessment is best when based on quantitative data that have been consistently and systematically applied within the site or across the landscape.

SSI reviewed existing literature and interviewed springs managers about springs ecosystem assessment approaches. This information was integrated to develop the comprehensive, quantitative and expert opinion-based SEAP. It provides stewards with information on the ecological status or condition of a springs ecosystem, as well as the risks and restoration potential of a broad array of associated resources, in relation to the administrative context of springs. Risk is interpreted as the potential threat or the "condition inertia" (the inverse of restoration potential) of that variable. In other words, what is the probability that variable will remain unchanged?

The SEAP report is based on the conceptual ecosystem model developed by Stevens and Springer (2004; Fig. 1.05), and incorporates information from on-site inventory, literature review, and interviews with the resource manager(s). SEAP can be conducted in several ways:

- As a rapid, in-office assessment developed by a manager with good understanding of the site,
- The result of a brief (10-20 minute) Level 1 field examination of the site, or
- Incorporating information from a Level 2 inventory, conducted by a team of 3-4 experts during a comprehensive (usually a 1-2 hour) site visit.

A SEAP report is useful for evaluating stewardship options within an individual springs ecosystem. It is also useful for monitoring the effectiveness of rehabilitation treatments and assessment of conditions or stewardship needs among many springs across a landscape.

The SEAP report ranks the condition (or value) of six subcategories, and the risk to that subcategory. The six variable categories are: 1) Aquifer and Wa-

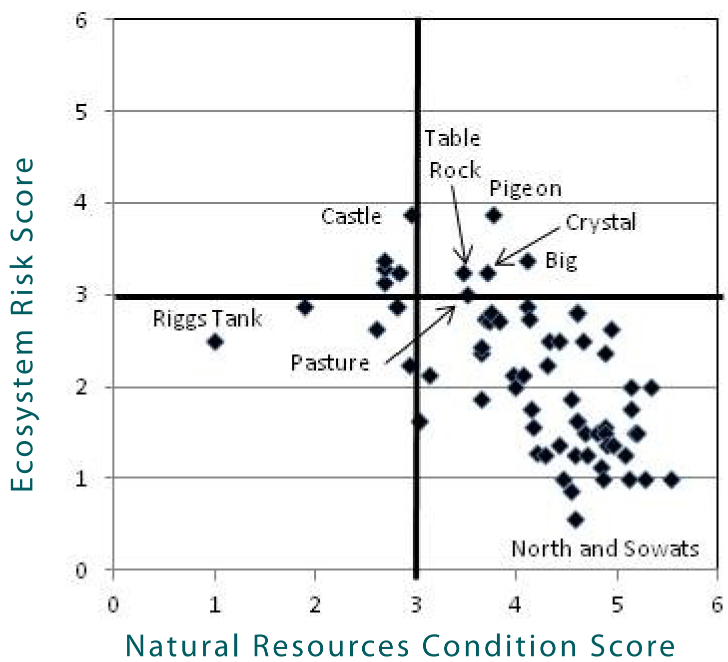


Fig 2.17: SEAP analysis of anthropogenic ecosystem risk in relation to natural resource conditions for springs within a land unit. Springs in or near the upper right quadrant are in good ecological condition with elevated risk, therefore may warrant stewardship attention (Ledbetter et al. in press).

ter Quality, 2) Site Geomorphology, 3) Habitat and Microhabitat Array, 4) Site Biota, 5) Human Uses and Influences, and 6) the Administrative Context under which the spring is managed in relation to desired conditions.

Each category is scored on the basis of 5-8 subcategory variables, which are ranked on a 0-6 scoring scale. Categories 1-5 are evaluated by the inventory team, while Category 6 (Administrative Context) is evaluated through a discussion with the land or resource manager that focuses on the steward's expectations, desires, and level of satisfaction with the current status or "performance" of the springs ecosystem. Categories 1-4 are natural resource categories, scored through expert opinion. Subcategory scores within categories 1-4 are averaged and plotted against the total Category 5 Human Risks scores to produce the overall Category scores. The ecological health score is evaluated in relation to human influences, which then can be compared with the stewardship plan for the site. The field forms and the SEAP criteria are available in Appendix A and on the Springs Stewardship Institute website (http://springstewardshipinstitute.org/downloadsandpdfs/).

Using the SEAP

SSI has applied the SEAP on individual springs as well as in regional landscapes (southern Alberta, southern Nevada, northern Arizona, and elsewhere; e.g. Springer et al. 2014; Ledbetter et al. in press). SIA conducted a Level 2 inventory and a SEAP analysis of Montezuma Well, a large limnocrene (pool-forming spring) in Montezuma Castle National Monument in central Arizona (Fig. 2.16). The SEAP indicated that the site was in fairly good ecological condition, and intensive recreational visitation are desired by the springs steward (the National Park Service). However, the Well is threatened by regional groundwater pumping, and is visited by many thousands of tourists each year, which likely interrupt use of the springs by some wildlife.

In large landscapes, comparison of the natural resources condition scores with the human risk scores provides an initial list of which springs are likely to warrant management attention (Fig. 2.17).

For example, SSI inventoried springs on Kaibab National Forest in northern Arizona. A SEAP analysis revealed a suite of springs that had relatively high ecological condition or value but had moderate levels of risk due to anthropogenic impacts (Fig. 2.16). SSI recommended this group of springs to be considered for management attention. Subsequently, the National Forest Service proposed and conducted restoration actions at the highest priority springs.

Thus, the SEAP is broadly and multi-culturally effective, efficient, comprehensive, and specifically informative for virtually all spring ecosystems. Analysis of large suites of springs in several studies have indicated strong responses of springs types and habitats to anthropogenic stressors; particularly groundwater depletion, flow diversion, geomorphic alteration, livestock grazing, and nonnative species introductions (e.g., Springer et al. 2014; Paffett 2014). SEAP analyses can be used to guide ecosystem rehabilitation planning and implementation, and the inventory data provide a useful baseline against which to measure the success of rehabilitation efforts.

CONCLUSIONS

SSI's integrated springs inventory, assessment, and information management methods are easily and freely accessible, and resulting data are securely stored in the Springs Online database (http://springsdata.org/index.php), which provides personalized, freely available, password-protected entry and reporting of springs-related data. Springs Online also allows neighboring springs stewards to share information about aquifers and springs in a common context and language. This opportunity has been conspicuously missing from most other inventory and assessment approaches for springs within groundwater basins.

In this chapter we described issues related to site selection, staff composition, logistics planning, inventory variables, data collection protocols, the equipment needed for conducting springs inventory, assessment, and information management. The field data sheets in current use by SSI are included in Appendix A, and can be downloaded at http://springstewardshipinstitute.org/downloadsandpdfs/.

Fig. 2.18: The heavily manipulated Castle Spring was identified as a recommended restoration site through the SEAP process, and selected for restoration by the Kaibab National Forest. Photo by Molly Joyce.

Chapter 3

Springs-Dependent Species

Photo by Erik Gaugher

Aridland springs are renown as hotspots of biological diversity (Williams and Danks, 1991; Shepard, 1993; Botsaneau 1998; Minckley and Unmack, 2008; Hershler 2014). Some springs have the highest levels of biological productivity and species density recorded, with productivity exceeding 6 kg/m^2/yr (Odum 1957). This stands in marked contrast to the low level of productivity of most arid regions, which may only be a few grams/m^2/yr. Springs often are tightly packed with plant, invertebrate, and some vertebrate species, commonly supporting several plant species/m^2, again much in contrast to the surrounding uplands (e.g., Ledbetter in press).

The abundance of individual springs-dependent species (SDS), such as hydrobiid springsnails, may exceed 100/m^2 (Hershler 2014). In part, the reason that some springs support such high species density and abundance is related to habitat heterogeneity: large gushets, hanging gardens, and other types support up to a dozen different microhabitats, each with its own suite of SDS and facultative species (Stevens and Springer 2004; Springer and Stevens 2008). Several evolutionarily stable types of springs exist, including some hillslope springs, pool-forming limnocrenes, springfed wet meadow fens or ciénegas, and hanging gardens. Such sites are known for high levels of endemic biodiversity and, in some cases, top-down trophic cascades (e.g., Montezuma Well in central Arizona - Blinn 2008). In addition to the species diversity attributes, springs often function as keystone ecosystems, ecologically highly influential habitat patches that play a disproportionately important role on adjacent uplands (Perla and Stevens 2008).

SDS are species that require springs for one or more critical life history phases, and such species often are closely adapted to the microhabitats in which they occur. More than 80% of the more than 120 springsnail species in North America are localized endemics, habitat specialists that cannot exist outside of their individual springs (Hershler 2014). Adaptation and single-site endemism also occurs among some SDS plants in Arizona (Arizona Rare Plant Committee 2006), many aquatic true bugs (Hemiptera) in the Grand Canyon ecoregion (Stevens and Polhemus 2008), cyprinodontid pupfish (Brown and Feldmeth 1971, Echelle et al. 2005), the invertebrate and fish fauna of the Great Australian Basin in Australia (Knott 1998), and seafloor vent springs. We estimate that more than 10 percent of the federally listed species in the United States are SDS, and SDS include a large number of rare species, including some that are new to science (e.g., Stevens and Bailowitz 2009; Hershler et al. in press). Unfortunately, springs-dependence is not typically noted on specimen collection labels or in conservation status reviews, making development of regional SDS lists difficult, and hindering understanding of the role of springs biodiversity at coarse spatial scales.

Given the extraordinary biodiversity and abundance of highly adapted and often rare biota at springs, improved understanding of the richness of SDS in Arizona is warranted. Here we provide an overview of the assemblages of species that may be of interest in springs stewardship efforts and we describe how, at some springs, species interactions intimately shape those assemblages. We have compiled a list of all plants, invertebrates, and vertebrates encountered at Arizona springs in relation to the habitats and regions they occupy, water chemistry, and elevation range at Springs Online. This dataset is increasing in value as more partners contribute to it. Such information is useful for planning species recovery or translocation into restored springs and can inspire springs stewards to provide better protection of their springs. In addition, SSI provides an easy-to-use, online SDS database into which those who are interested in springs-dependence among biota can contribute, and access a more complete list of SDS and associated springs information.

Plants

Behind California and Texas, and with more than 3,512 species, Arizona has the third highest number of native plants of any US state (Stein 2002). Approximately 10% of the state's flora is facultatively restricted to riparian habitats that make up less than 1% of the land area (e.g., Stevens and Ayers 2002). That SDS plants make up nearly half of those species is surprising because springs habitats make up less than 0.01% (one ten thousandth) of the state's landscape. This means that, on average across the state, springs support significantly greater species densities than do Arizona uplands (Ledbetter et al. in press). Such tight species packing at springs also has been reported in southern Nevada (Abele 2011, Ledbetter et al. 2012) and in Alberta (Springer et al. 2014). Unfortunately, an estimated 15% of Arizona's plant species are at risk of extinction, including SDS plants (Stein 2002).

Springs are places where many upland and SDS plants co-occur, with facultative upland species occurring around the periphery, contributing further to the high levels of species packing at springs. Some species, such as wetland monkeyflowers in the genera *Mimulus* and *Erythranthe* are commonly encountered at springs throughout the West, but occur more broadly in wetlands and along slow-moving streams. In contrast, some SDS plants, such as helleborine orchid (*Epipactis gigantea*) that are widely distributed across the West, occur virtually exclusively at springs. Lastly, a few Arizona SDS plants are locally endemic, tightly restricted to just one or a few springs (e.g., McDougall's flaveria, *Flaveria mcdougallii*, Fig. 3.01; Spence 2008). This same biogeographic pattern holds for springs dependent faunae as well, as discussed below.

Fig. 3.01: McDougall's Flavaria (*Flaveria mcdougallii*) is endemic to Grand Canyon, found only in alkaline, Mississippian-Cambrian aquifer springs along the Colorado River between miles 137 and 178 below Glen Canyon Dam. Although abundant within its limited habitat, it is considered imperiled.

Including the above-mentioned McDougall's flaveria at a few dozen alkali springs in central Grand Canyon, Arizona hosts a number of unique or rare SDS. These include Navajo sedge (*Carex specuicola*) at hanging gardens in the Four Corners area, and a group of ciénega species, such as *Bidens laevis* (an aquatic aster at Del Rio and a few other

Fig. 3.02: A yellow form of Cardinal Monkey Flower (*Mimulus cardinalis)* is found at Vasey's Paradise spring in Grand Canyon.

northwestern Arizona springs), *Budleya* (found perhaps only at one site in Tucson), and Arizona eryngo (*Eryngium sparganophyllum*), at Pakoon Springs. Propagation of such rare species by the state's several botanical gardens should be encouraged so that propagules can be provided to appropriate springs rehabilitation projects.

Nonnative plant species also are commonly encountered at springs, sometimes in great abundance. One would think that a great concentration of native species would protect springs from invasion by nonnative species, but only a slight amount of disturbance is required to allow weeds to colonize, and some weed species colonize even in the absence of disturbance (Stevens and Ayers 2002).

Invertebrates

A great host of native, endemic, and rare aquatic and wetland macroinvertebrates exists at Arizona springs. While some of these species have attracted research attention (e.g., the endemic Montezuma water scorpion, *Ranatra montezuma*, Raunk and Blinn 2008), others remain poorly known, and many springs-dependent invertebrates have yet to be described. Groups such as Turbellaria flatworms, Physidae snails, water mites (Acarini), *Hyallela* amphipods, and several families of shore flies (e.g., Ephydridae, Dolichopodidae) have not received enough taxonomic attention for us to understand how many SDS occur in Arizona.

Among aquatic SDS insects, taxa that are particularly likely to undergo endemism at springs include: a few dragonfly species (e.g., the newly discovered masked clubskimmer, *Brechmorhoga*

Fig. 3.04 *Abedus breviceps*, a water bug found only in a single spring-fed stream in central Grand Canyon.

pertinax in Grand Canyon, Stevens and Bailowitz 2005, Fig. 3.04); aquatic true bugs (the aforementioned Montezuma water scorpion, as well as *Ochterus rotundus* and other Hemiptera - Stevens and Polhemus 2008); dryopid beetles (particularly riffle beetles, Elmidae); and wetland ground beetles and butterflies (e.g., the nokomis fritillary, *Speyeria nokomis*).

As a list of Arizona's invertebrate species has not been developed, we cannot yet understand the relationship between springs and non-springs insect biodiversity; however, many aquatic invertebrates are found primarily or exclusively at springs.

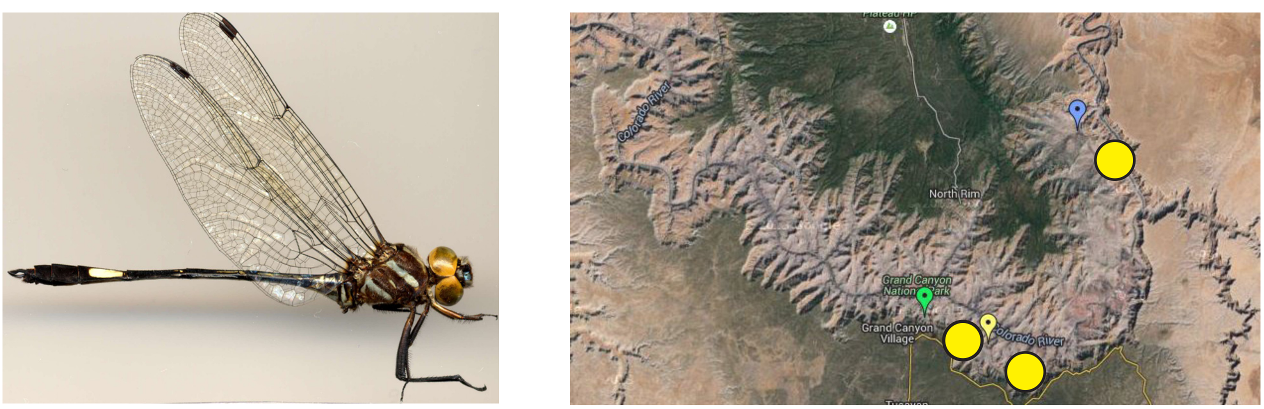


Fig. 3.03: Three subspecies of masked clubskimmer dragonfly (*Brechmorhoga pertinax*) occur from Mexico into South America, and it has been reported there as rarely entering the US in southeastern Arizona. A newly discovered reproducing population at springfed streams in central Grand Canyon may represent a new, springs endemic subspecies.

Fig. 3.05: Springsnails (*Pyrgulopsis)* have an extremely high rate of local endemism, with more than 80% of species restricted to one or a few springs.

The best known invertebrate SDS are hydrobiid springsnails in the genera *Trionia* and *Pyrgulopsis (*Fig. 3.05*)*. The latter genus is enormously diverse, with more than 120 species in North America, and is remarkable both for its frequency of local endemism (>80% of the species are restricted to one or just a few springs) and for its conservation status, with at least 6 species federally listed or proposed for listing (Hershler 2014). In Arizona, the San Bernardino springsnail (*Pyrgulopsis bernardina*), the Three Forks springsnail (*P. trivialis*), and the Page Springs springsnail (*P. morrisoni*) either are currently federally protected or are proposed for federal protection. All are restricted to one or several springs.

Fig. 3.06: *Cicindela hemorrhagica* (Grand Canyon Wetsalts Tiger Beetle) is endemic to Grand Canyon. They sit upright, attentively searching for prey and enemies along the edge of springfed streams. See http://springstewardshipinstitute.org/tiger-beetle/ for more information. Photo © Erik Gauger.

Although nonnative plant species richness is relatively high, relatively few nonnative aquatic invertebrate species occur at Arizona springs. Some nonnative invertebrate species at springs appear to be rather innocuous land mollusca (e.g., *Limus maximus* at Coyote Springs near Flagstaff). However, crayfish have been introduced into many Arizona waterways, and exert devastating predatory impacts on springs ecosystems. Crayfish are long-lived, generalist predators that are highly fecund, mobile, and resistant to nearly all forms of control, traits that contribute to their invasion success. Crayfish species of concern in the state are middle-upper elevation *Orconectes virilis* and lowland *Procambarus clarkii*. The latter species is native to the Mississippi River and is widely distributed across southern United States and southern Europe, everywhere severely affecting aquatic ecosystems (Scoppetone et al. 2005; Cruz et al. 2006; Kilburn 2012). Crayfish prey on springs biota, consuming all manner of life, including invertebrates, amphibians, and even garter snakes (*Thamnophis spp.*).

Although habitat connectivity is a key conservation principle in large landscapes, the often isolated nature of springs ecosystems can protect springs from invasion of nonnative aquatic species such as crayfish. Nonnative species presence in nearby streams is an important consideration when planning springs restoration projects; connecting springs outflow to the streams may result in nonnative species invasion into the springs.

Vertebrates

Arizona's SDS native fish and herpetofaunae (amphibians and reptiles) include many endemic and rare species. Fully one third of the state's fish species require springs, living only in spring-fed streams or only occurring at springs. Many of the state's native fish species have wide thermal and water quality tolerances in smaller streams at lower to middle elevations, but the base flow of nearly all of our streams is derived from springs.

Native amphibians that commonly or exclusively occupy springs and springfed streams include:

Fig. 3.07: The American Dipper (*Cinclus mexicana*) is the only springs-dependent bird species in the Southwest. They are found at cold water spring-fed streams, and make moss nests behind waterfalls in gushet springs.

Fig. 3.09: Leopard frogs (*Lithobates spp.*) were commonly found at helocrene springs throughout Arizona, but have been much reduced by habitat loss, disease, and the introduction of nonnative species.

pool-dwelling tiger salamanders (*Ambystoma* spp.), ciénega-inhabiting and springfed stream-dwelling leopard and Tarahumara frogs (*Lithobates* spp.), and canyon treefrogs (*Hyla arenicolor*), and several toad species (Anaxyzrus Arizona toad).

While no birds or mammals are endemic to Arizona springs, species such as the American Dipper (*Cinclus mexicana,* Fig. 3.07) and voles (*Microtus* spp.) are commonly found at springs and in springs-supported habitats, particularly at their lower elevation limits. American Dippers make moss nests behind waterfalls in springfed streams at their lowest nesting elevation limits (e.g., Matkatamiba Canyon in Grand Canyon, elevation 600 m).

Nonnative vertebrate species likely to be encountered at springs are primarily aquarium, bait, and game fish, all of which wreak havoc on native assemblages of invertebrates and fish. Species such as mosquitofish (*Gambusia affinis*), tilapia (*Tilapia* sp.), and centrachid bass, bluegills, and other game fish species, prey upon and compete with native SDS. Management of such species requires long-term commitment to consistent removal, or entirely dewatering the site and rebuilding the ecosystem, such has been accomplished at School and other springs in Ash Meadows National Wildlife Refuge in southern Nevada.

Fig. 3.08: Bullfrog (*Lithobates catesbeianus*). Photo cour
esty of SIA © 2015.

Like crayfish, bullfrogs (*Lithobates catesbeianus*) devastate local assemblages through predation and competition. Bullfrogs are particularly difficult to remove because it requires regular (e.g., monthly) control efforts continued for several years. At Pakoon Springs, four years of bullfrog control greatly reduced the population to just a few individuals (Burke et al. 2015).

Springs as Keystone Ecosystems

Springs function as keystone ecosystems, occurring as small patches of ecologically influential habitat within larger, surrounding upland habitats. For example, migrating birds use springs as stopover habitat (Stevens et al. 1977), and many of the birds and larger mammals within a region come to springs for water each day.

Climate Change Implications

Climate change and regional warming are likely to reduce existing infiltration and aquifer recharge, and will increase uncertainty about thermal, disturbance, and other habitat variables. Rehabilitation of springs is one form of adaptation to these uncertainties: aquifer protection and rehabilitation of the springs they support helps guarantee that

Fig. 3.10: Arizona centaury (*Centaurium calycosum*) is a wetland plant commonly found at Arizona springs. Photo couresty of SIA © 2015.

these ecologically important points in the landscape continue to provide refuge and habitat for the many species they support. If the aquifer is in good condition, springs restoration efforts can be successful (Davis et al. 2011). Nevertheless some springs types, particularly rheocrenes, are likely to be scoured by floods that may sweep away gabions and other structures constructed to restore or enhance habitat. Successful springs rehabilitation efforts can provide replacement or additional habitat for species of management concern.

Conclusions

Nearly all studies of springs ecosystem ecology emphasize their biodiversity significance. Despite the miniscule total area of springs in the United States, more than 10 percent of the nation's endangered animal species are springs-dependent. High concentrations of rare species also occur at some springs. Ecological threats to springs from groundwater pumping, source alteration, and climate change are many, and are increasing through time (Minckley and Deacon 1991; Stevens and Meretsky 2008). Rehabilitation of springs ecosystems can help protect our native biodiversity, both at springs and in surrounding landscapes, and can be an effective strategy for adapting to climate change.

Chapter 4

Restoration Planning

Defining restoration goals is essential before beginning a project, as goals may vary from restoration of one or a small suite of ecosystem elements or processes, to full rehabilitation of the site to presumed pristine conditions. Meeting with all concerned stakeholders is necessary to reach consensus on the issues, rationale for action, expected outcomes and benefits, costs, monitoring needs, and consequences if the effort is not successful. There must also be future commitment to the project that includes monitoring. Recognizing in advance potential pitfalls and consequences of actions can greatly help focus the planned activities. Of over-riding importance in such planning is understanding the type of springs ecosystem under consideration for rehabilitation, because creating habitats that are inappropriate for a given springs type will likely mean additional maintenance costs that may not be sustainable over time.

How, by whom, at what cost, and at what schedule are defined in the rehabilitation proposal and the project workplan. Individuals conducting springs rehabilitation may undertake many actions without consultation, but guidance from experts often improves chances of project success. Agencies planning to undertake springs rehabilitation are required to undergo significant review to ensure the importance, cost-effectiveness, logic of the plan. Data management and monitoring are necessary for rehabilitation activities because the feedback helps improve stewardship over time. While exhaustive premeditation may not always be necessary, forethought and planning helps guarantee project success.

The Planning Process

Like all processes that require forethought and financial investment, springs ecosystem rehabilitation is most likely to succeed when based on a logical progression of actions (Fig. 4.01). The elements of springs rehabilitation planning and implementation include: assembling the stewardship group (managers, agencies, Tribes, concerned organizations and individuals); introducing the problem and challenges; compilation and understanding of background, inventory, and assessment information; brainstorming and discussion about options; development of a plan, including outreach and information management; securing funding for both management actions and monitoring; conducting or overseeing implementation; and then monitoring and feeding back information on progress to improve stewardship. An open, inclusive process helps all concerned with the project understand the process and bring out new ideas and insights that may facilitate it.

By addressing these questions and issues in a clear and straightforward manner, the stewardship planning and restoration implementation team can develop an understanding of the full array of challenges, and prepare and implement a rehabilitation plan, a detailed scope of work plan, and a monitoring plan.

Planning Questions (See Appendix B for worksheet.)

After fully reviewing administrative issues, literature, inventory and assessment information, the springs stewardship group should address the following 18 questions and issues:

1. What is the problem?
2. Can the problem be fixed?
   - What is the administrative context?
3. Who cares and why?
   - What is the membership of the stewardship planning and implementation team?
   - Which other individuals and groups are involved or should collaborate?
4. How will the rehabilitation project be funded in both the short term and long-term?
5. What is the urgency of this project?
6. What are the desired future conditions?
   - Distinguish among flowing (lotic) versus non- or slow-flowing (lentic) springs types
7. What are the rehabilitation goals (broad future vision for the ecosystem)?
   - This will vary in relation to the type of springs ecosystem
   - Further refine understanding of desired microhabitats
8. What are the rehabilitation objectives and options?
   - What are the specific management goals (e.g., single species or habitat enhancement, versus whole-ecosystem rehabilitation)
9. If multiple uses are desired, what balance of uses is best and how can those uses best be accommodated?
10. What is likely to be the cost and what are the sources of funding?
11. What is the time line?
    - Including pre-treatment monitoring
    - Implementation at 10, 30, 60, 90 and 100% completion
    - Include long-term, post-treatment monitoring
12. What are the regulatory and compliance issues and how are they to be resolved?
13. Who is responsible for implementation and oversight, and on what schedule?
14. How will information management and reporting be achieved?
15. How will monitoring feedback be used to improve stewardship?
16. What contingency planning is needed?
    - What if……happens?
17. What additional outreach, partnerships, and funding are needed?
18. What long-term stewardship issues need to be resolved and how will that resolution take place?
    - How will the long-term effectiveness of the project be guaranteed?

Restoration and Planning Process

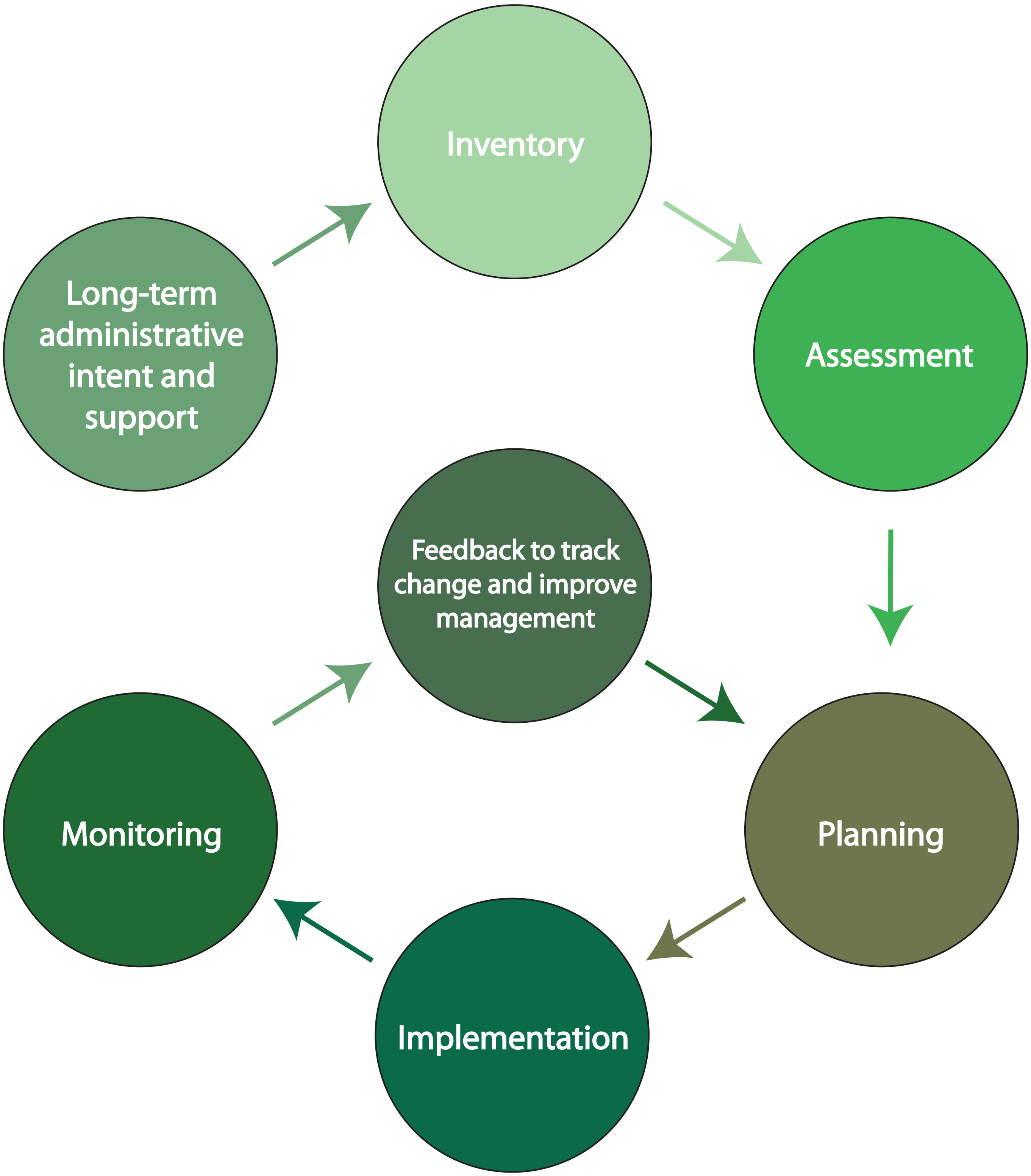


Fig. 4.01: The springs ecosystem restoration and planning process.

Partner Engagement

Moving springs stewardship from inventory and assessment, to recommendations about management, to implementation may involve conversation with diverse stewards, experts and governing officials. Such discussion often involves integration of restoration planning into processes and activities going on across the landscape. A key to success in springs ecosystem rehabilitation is involving appropriate partners through the entire process. On federal lands, such partners will be diverse, including the U.S. Fish and Wildlife Service, the Arizona Game and Fish Department, the Army Corps of Engineers, affected Native American Indian Tribes, the State Historic Preservation Officer, as well as contractors for compliance and construction, and independent experts. With all appropriate partners engaged, the likelihood of project success is much greater. The rehabilitation team should collectively visit the site to ensure that all participants understand the project dimensions and needs. As the team may be a diverse group, the team leader should be open to and prepared for serious and perhaps contentious debate about the rationale, methods, and logistics of rehabilitation and monitoring.

Compliance

Governmental agencies are subject to regulations on natural resources, as described above, some of which apply to private lands as well. These regulations require an often daunting amount of consideration and paperwork, which is costly and time-consuming, but hopefully in the end allows well-framed projects to succeed. The extent of compliance should be thoroughly investigated before undertaking a springs rehabilitation effort.

National Environmental Protection Act (NEPA) compliance is needed for project approval when rehabilitation takes place on federal land. NEPA compliance may involve preparation of an environmental assessment, Arizona State Historic Preservation Officer compliance with Section 106 of the National Historic Preservation Act and Arizona State compliance, U.S. Army Corps of Engineers and EPA compliance with Clean Water Act Sections 401 and 404, U.S. Fish and Wildlife Service compliance with the Endangered Species Act, and consultation with Native American Indian Tribes. In situations potentially affecting many constituents, other agencies, and the public, an environmental impact statement (EIS) may be required. The latter is an intensive, expensive, and sometimes contentious federal process that may require years to complete.

Prioritization: SEAP

The SSI SEAP analysis provides insight into stewardship issues at a single site, and also can be used for prioritizing stewardship among a large number of springs across large landscapes, such as US National Forests, US National Parks, Bureau of Land Management units, large conservation networks (e.g. the Sky Island Alliance landscape), or large ranches (see http://springstewardshipinstitute.org/springs-1).

The results of SEAP analysis provide quantitative and graphical opportunities for the springs stewards to understand relative conditions and risks of an individual springs ecosystem over time, or those of springs across a landscape at one time or over time (i.e., through monitoring data). The SEAP analysis was also designed to document changing site conditions following a management activity. For individual springs, a SEAP analysis provides a clear indication of major ecological impacts, and repeated use of SEAP over time can be used to monitor the results and success of ecological rehabilitation actions. For large landscape stewardship prioritization, the cumulative SEAP natural resources condition score (combined average of categories 1-4) can be compared with the human influences category risk score. Plotting those data usually produces a graph that reveals a negative relationship, with some sites in poor ecological condition and high risk, and others in better ecological condition and at lower risk (Springer et al. 2014; Fig. 2.16).

Refined Prioritization

A SEAP analysis provides general guidance on stewardship opportunities within a single site, or prioritization among sites within a landscape, but additional discussion with the rehabilitation team is needed to ensure the needs of the team members are met and development of an appropriate work plan. In the case of rehabilitation planning on a single site, the SEAP will have identified the primary "red flags" and will have recommendations about specific management actions. Discussion among the stakeholders may further refine within-site priorities and development of a scope of work.

In the case of a large landscape with many springs, the priorities of the stakeholders are likely to be more diverse, and consensus on prioritization criteria for rehabilitation planning may need to be refined. Paffett (2014) used the SEAP information on springs in northern Arizona National Forests to focus a springs rehabilitation planning discussion among Forest Service staff. That group identified 10 criteria as being important to rehabilitation planning (Table 4.01). Those criteria involved access, ownership of water rights, presence of endangered and exotic species, critical habitat, and cultural properties, ease of restoration action, benefits to wildlife populations, and the influence of nearby urban areas. Formulae for each of these criteria were developed using springs inventory and SEAP data, and each criterion was ranked by the Forest staff. The sum of weighted scores was used to prioritize rehabilitation management on 153 springs,

Table 4.01 Stewardship prioritization criteria and weighting values for two northern Arizona National Forests, based on interviews and meeting with forest managers (Paffitt 2014).

Stewardship Criteria	Weighted Importance Value
1) Ease of restoration	1
2) Water rights ownership	0.9
3) Presence of federally listed species	0.8
4) Ease of return to natural sphere of discharge	0.7
5) Absence or ease of eradication of exotic species	0.6
6) Occurrence of springs in priority watershed	0.5
7) Presence of culturally or historically sensitive springs	0.4
8) Ease of exclusion of ungulates from source	0.3
9) Ease of improving access by native animals	0.2
10) Proximity to municipalities	0.1

and high priority springs were identified for potential management attention. Preliminary results were shared with the Forest Service staff, and the final list was developed for Forest planners.

This prioritization refinement process may be improved by recognizing and discussing inherent conflicts among criteria. For example, the ease of restoration was interpreted by the managers as proximity to roadways because remote springs require more costly staff and equipment transport. However, springs near roads may be inherently more difficult to rehabilitate because of continued impacts on geomorphology, water quality, wildlife, fugitive dust, and other factors. Also, while springs near municipalities may serve as indicators of urbanization impacts on aquifer and groundwater quality, springs that are closer to towns are more likely to sustain recreation or water resource exploitation impacts. Nonetheless, the approach of identifying stewardship criteria and ranking them provides a clear prioritization process for management planning.

Contingency Planning

Some kinds of events can be predicted based on the landscape setting of the springs under consideration for rehabilitation. For example, flooding is expected at rheocrene springs, and rockfall is likely to occur at hanging gardens. Based on the type of springs ecosystem, the status of the aquifer, the proximity of springs to ranches, recreational use intensity, nonnative species distribution, the impacts of and solutions to dewatering, fire, trespass cattle grazing, vandalism, and exotic invasions can be anticipated and potentially mitigated. Consideration of expected impacts should be discussed in developing the overall site plan. However, unanticipated impacts are likely, and therefore having the team continue to meet and discuss monitoring results is important to maintain the site over a longer time period.

Conclusions

Development of a springs ecosystem rehabilitation plan is important to encourage dialogue among collaborating parties, and to clarify relationships, the administrative context, and consider as much as is possible or reasonable the project scope, needs, timing, costs, information management, and monitoring contingencies. An open, inclusive, flexible, and well thought out approach all help to ensure success.

Photo by Rich Rudow

Chapter 5

Springs Restoration

Ecological restoration or rehabilitation involves actions that improve springs stewardship, including modification of site characteristics, processes, species, and management. While many Arizona aquifers around urban and agricultural areas have been drawn down, many throughout the state are still relatively unimpaired. Springs emerging from these unimpaired aquifers often are remarkably resilient and can respond positively to direct management actions. Restoration options can range from relatively minor activities, such as re-establishment of native species, removal of small manmade structures like spring boxes, tanks and piping, or constructing a trail to limit hillslope erosion. Where natural drainage and geomorphology are intact and physical conditions allow desired conditions to recover, it may only be necessary to remove or modify infrastructure. At springs with severe impacts, larger-scale physical manipulation and reconstruction of site geomorphology may be appropriate.

As we recommend in previous chapters, careful attention to inventory, assessment, and information management, and forethought in planning are likely to improve the success of restoration, monitoring, and sustainable stewardship. Restoration involves remediating the impacts of habitat alteration through physical, on-site actions and reduction of nonnative species impacts, but should be undertaken after inappropriate management practices have been rectified, as identified in the restoration planning process.

After the major stressors have been removed, the most important restoration activities for springs include the following. 1) Restoration from livestock grazing impacts may involve improving bank stability, decompacting soils, controlling invasive species, and revegetation, but vary in relation to springs type and elevation. 2) Restoration of spring sources may help protect springs-specialist plants and animals, and can be accomplished through modification of geomorphology and flow regulation structures. In cases where water extraction is also desired, installation of a flow splitter can ensure water continues to emerge at the source (Fig. 1.15). 3) Spring brook channel restoration may be necessary if the spring channel is functioning unnaturally. If so, restoration options include restoring flow to historic channels, restoration of existing channels, or constructing new, geomorphically appropriate channels. 4) Restoration of marsh-forming (helocrene) springs often involves

filling ditches, preventing erosional head-cutting with grade control structures, eliminating erosional channels, removing drainage tiles or subgrade water diversion structures to increase groundwater depth, and replanting native wetland plant species. 5) Restoration of pool-forming (limnocrene) springs may range from correcting issues of stagnation and eutrophication, to geomorphic pool reconstruction. 6) Removal of undesired nonnative species (e.g., tamarisk, palms, Russian olive, and elms) may require heavy equipment, and reconstruction may be needed to prevent the return of undesired species. Fish barriers or weirs, and livestock exclosures also may be constructed to prevent nonnative vertebrate species impacts. 7) Restoration from recreation impacts may include soil regeneration from compaction, replanting vegetation, removing contaminants and nonnative species, and reducing visitor impacts by construction of trails and boardwalks, by restricting vehicular access, and where necessary eliminating camping or even closing sites to visitation.

Understanding the springs type and associated microhabitats is crucial for sustainable restoration success: construction of atypical microhabitats will involve some to much maintenance, and ultimately may not be successful. In this chapter, we summarize the challenges, methods, results, and lessons learned from restoration at the four most common springs types in Arizona.

Rheocrene—Hoxworth Spring

Coconino National Forest

This helocrenic rheocrene springs ecosystem is near Lake Mary, south of Flagstaff. A century of forest fire suppression, introduction of nonnative ungulates, and recent drought threatened the functionality of this wet meadow. Geomorphic reconstruction was successful.

Hanging Garden—Castle Spring

Kaibab National Forest

A rockshelter hanging garden in the North Kaibab District on the North Rim of Grand Canyon, this spring was historically used for livestock grazing, resulting in extensive damage. Effort of Tribal, USFS, and NGO collaborators rehabilitated the springs.

Hillslope - Pakoon Spring

Parashant National Monument

One of the largest spring complexes on the Arizona Strip north of the Grand Canyon, this spring has 10 sources. It was used for over a century as a cattle ranch, more recently as an ostrich farm. Rehabilitation of geomorphology and native vegetation restored natural function.

Helocrene - Ash Spring

Coronado National Forest

Ash Spring is a helocrenic hillslope spring at 1,873 meters (6,145 feet) elevation in the Chiricahua Mountains of southeastern Arizona. Partners restored use of the meadow by bats, birds, and amphibians.

Rheocrene Restoration

Hoxworth Spring, Coconino National Forest

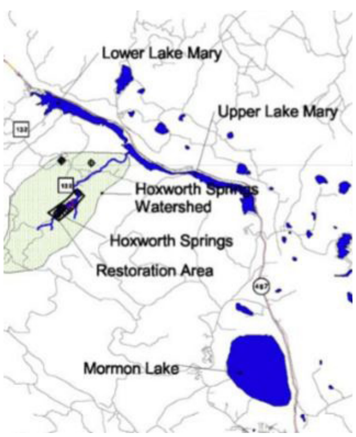
Description/Site Overview

Hoxworth Spring is a helocrenic rheocrene (wet meadow channel) spring that emerges at 2130 m (7000 ft) elevation near Lake Mary, south of Flagstaff on the southern Colorado Plateau in Coconino National Forest. The springs system emerges at a fault contact that crosses the drainage, wetting an otherwise ephemeral channel. The discharge of the spring varies strongly seasonally and among years, creating seasonally variable reaches of intermittent channel. The total habitat area supported by the springs varies from 0.5 to 1 ha.

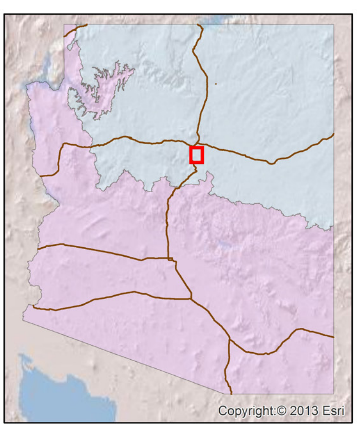
A century of forest fire suppression, creation of low head dams, tree harvesting followed by a half century without forest thinning, introduction of nonnative Rocky Mountain elk (*Cervus canadensis nelsoni*), and recent drought resulted in stream channel incision that threatened sapping of wet meadow habitat, loss of the helocrenic functionality, and invasion of ponderosa pine (*Pinus ponderosa*) into the meadow habitats.

Partners

Working closely with Coconino National Forest, and with funding from the Arizona Water Protection Fund, Northern Arizona University Hydrologist Abe Springer and his colleagues and students began the restoration of Hoxworth Spring in 1997.



Detail map courtesy of Abe Springer, NAU.



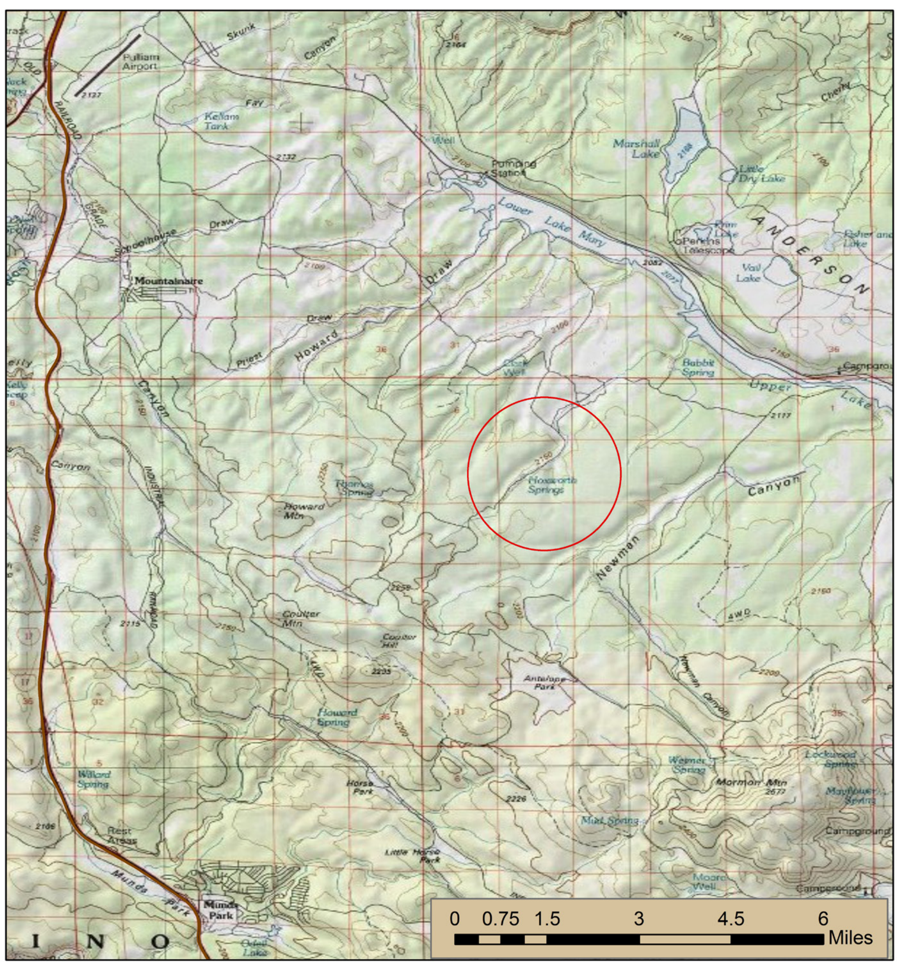


Fig. 6.01: Location of Hoxworth Spring in Mormon Lake Ranger District, Coconino National Forest, elevation 2144 meters.

Fig. 6.02: Channel and pool at Hoxworth Spring.

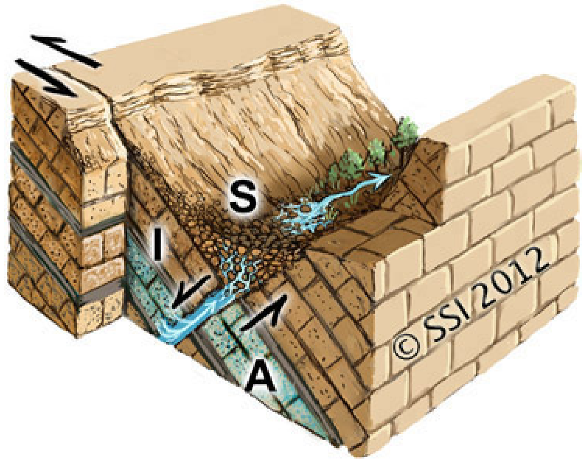


Fig. 6.03: Diagram of a rheocrene spring, A=aquifer, S=source, and I=impermeable layer. illustrated by V. Leshyk for SSI © 2012).

Goals and Conservation Targets

The goal of this project was to restore and repair an unnaturally straight, incised springs/stream channel to maximize the wetland and wildlife habitat area of the springs (Fig. 6.02). Water sources are scarce in this portion of Coconino National Forest, and ecological and geomorphological sustainability of the site were desired to better support plants and animal diversity.

Methods

The team carefully mapped the site to 0.5 m accuracy, monitored and modeled groundwater flow, as well as water quality and variability, and the proposed geomorphological restoration to Forest managers. Using the site map as a planning tool, the team brought in an earth mover to restructure the channel to a sinuosity that matched expected high flows. As a rheocrene springs ecosystem, it was assumed that rare large floods would shape channel geomorphology, into which the springs discharge would flow.

The team constructed channel barriers to elevate the base level of the stream and stem the incision

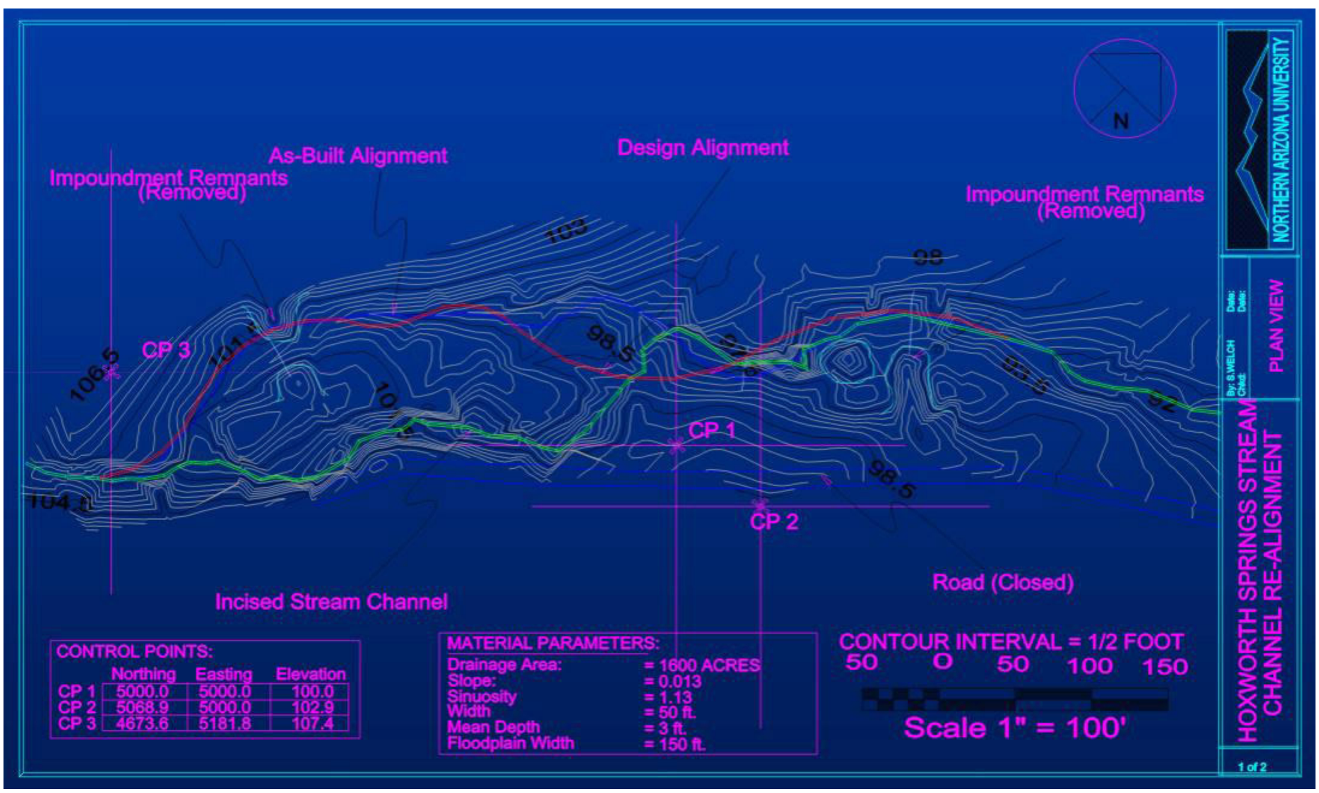


Fig. 6.04: Hoxworth Spring channel realignment plan developed by Northern Arizona University.

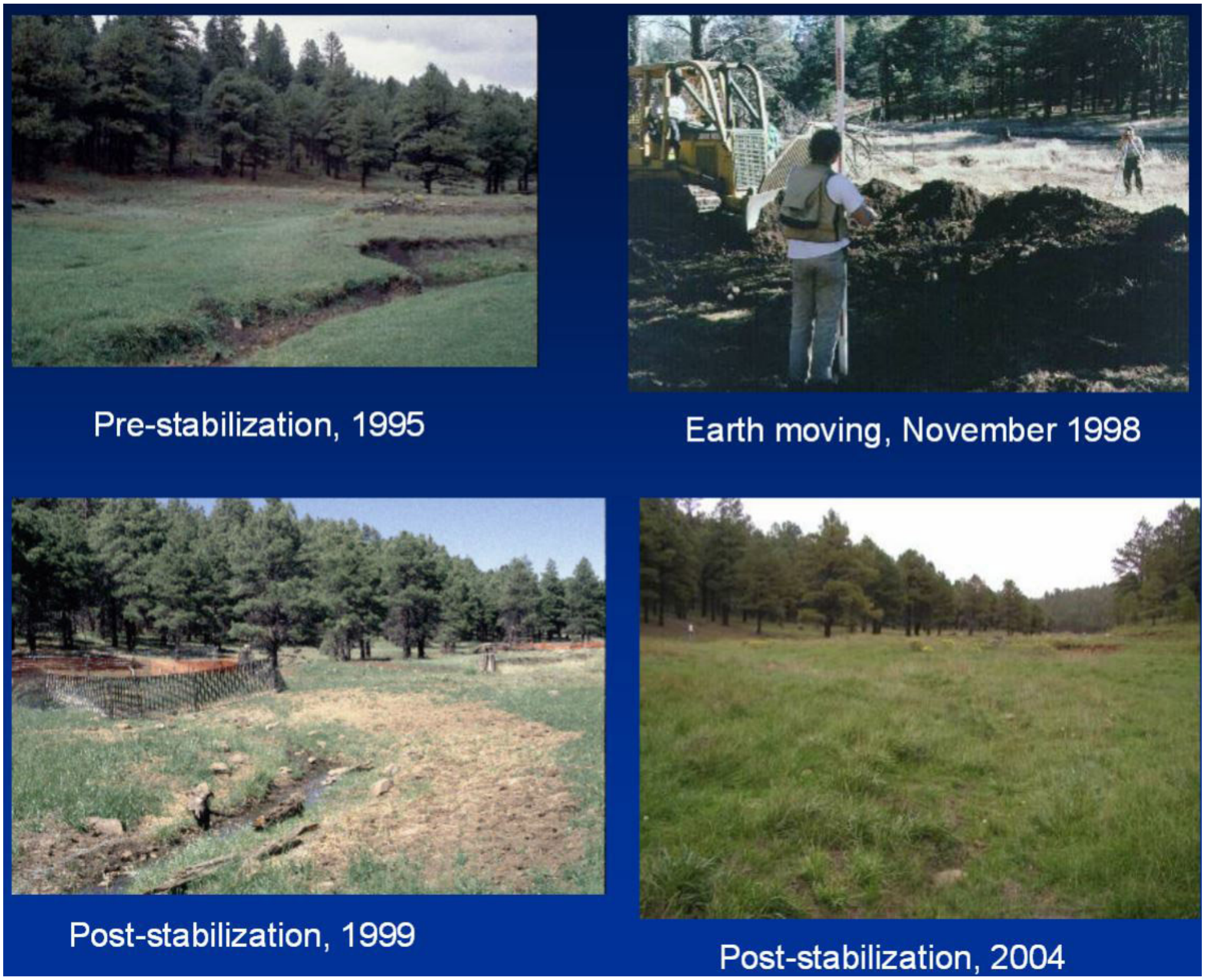


Fig. 6.05: Pre- and post stabilization of Hoxworth Spring, photos courtesy of Abe Springer.

process, and followed up on that construction with planting of native wetland sedges and other vegetation to function as bank stabilization.

Dr. Springer and his students subsequently conducted long-term monitoring of channel responses and springs flow, and followed up with improved groundwater modeling.

Results and Lessons Learned

One of the essential lessons learned from this project is that long-term monitoring data are needed prior to construction to clarify the scope of the restoration activities. Due to an extended dry phase of long-term climate fluctuations, discharge from the spring has been considerably less than expected. The drier climate has caused the length of intermittent flow in the reconstructed channel geomorphology to be less than planned. Also, intensive impacts from nonnative elk browsing combine to affect channel vegetation and bank erosion. Nonetheless, Hoxworth Spring now provides open water for wildlife and is functioning well as a riparian wetland.

This springs restoration project is successfully meeting the project objectives. In addition, it was a highly successful collaboration between federal and non-federal partners. It is an important test case for Coconino National Forest, which has expressed interest in improving springs stewardship. Long-term flow monitoring and groundwater modeling has served as an educational opportunity for a generation of NAU hydrology students, and has clarified responsiveness of this springs ecosystem to climate change. This site has become a classic case for improving understanding of how improved forest management by forest thinning may help improve springs discharge and enhance Forest wildlife habitat quality. Other excellent examples of rheocrene springs restoration include Anderson et al. (2003) and Marks et al. (2009).

Hanging Garden Restoration

Castle Spring, Kaibab National Forest

Description/Site Overview

Hanging gardens are abundant on the southern Colorado Plateau in northern Arizona. These springs often are geomorphically delicate features that can be easily altered by erosion, fire, livestock presence, and other anthropogenic impacts. A study of the burned Knowles Canyon hanging garden in southern Utah revealed slow vegetation and soil biota recovery 8 years after fire (Graham 2008), suggesting that the ecological integrity of hanging gardens may be difficult to restore.

Castle Spring is a rock shelter hanging garden in Kaibab National Forest on the North Kaibab District on the Arizona Strip. It lies at 2,195 m (7,200 ft) elevation, and has long been used for livestock watering and grazing. As a consequence the site contained much old, decomposing fencing, gates, and many buried and leaking pipes, a heavily disturbed parking area, graffiti on the backwalls, and a host of nonnative plants throughout the site. A hand-hewn ponderosa pine log watering trough was the only feature of historic value at the spring.

Partners

After receiving inventory and stewardship recommendations from SSI described in Chapter 2,

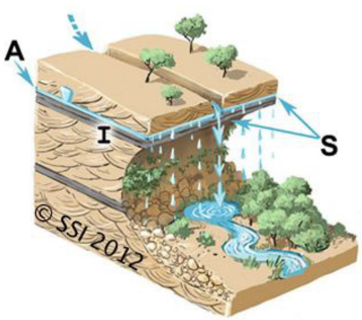
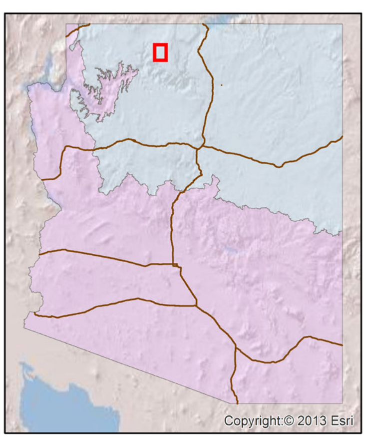


Fig. 6.06: Diagram of a hanging garden spring, A=aquifer, S=source, and I=impermeable layer. illustrated by V. Leshyk for SSI © 2012).



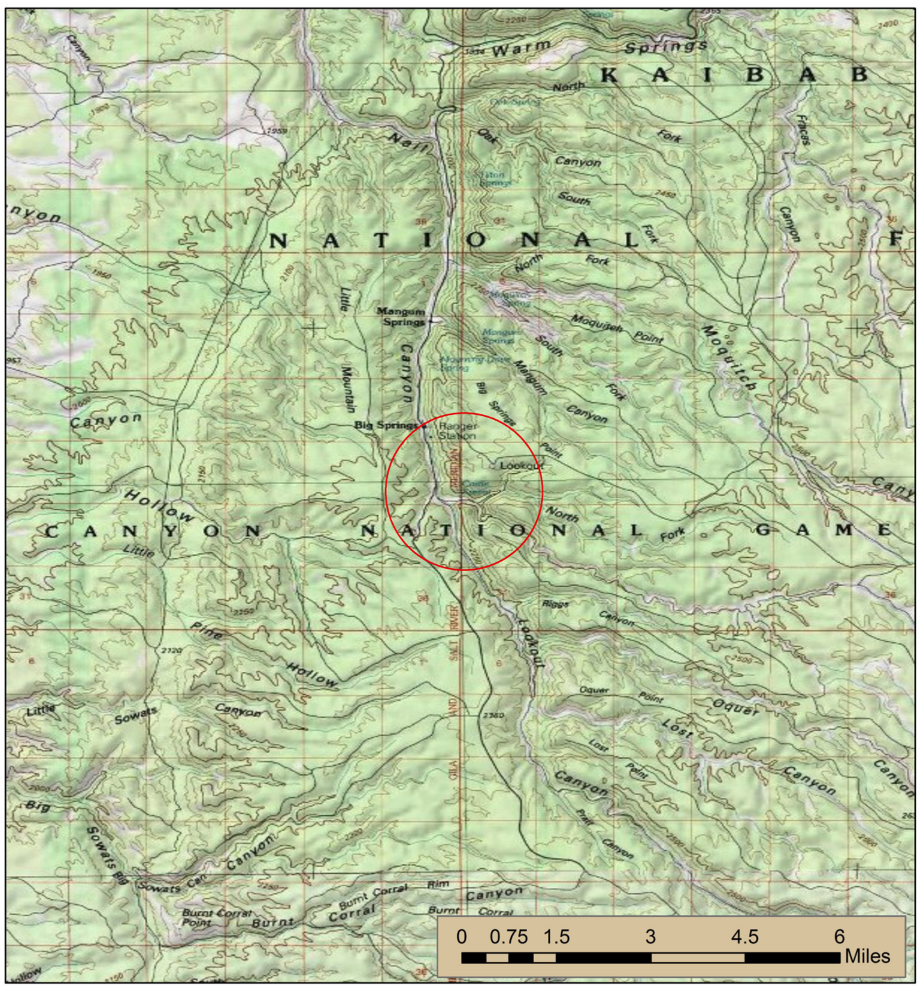


Fig. 6.07: Location of Castle Spring in North Kaibab Ranger District, Kaibab National Forest.

Fig. 6.08: Tribal partners helped to remove old corral fencing that was no longer functional.

the U.S. Forest Service selected Castle Spring as a restoration site. They convened a week-long meeting between the Forest Service, elders and youth from the Hopi Tribe and the North Kaibab Piute Band, Grand Canyon Trust, and SSI to plan and conduct rehabilitation.

Project Goals and Conservation Targets

The objectives of the restoration project were to: 1) cooperatively plan springs restoration with Forest Service, the Tribes, and SSI; 2) directly implement the plan with the assistance of the collaborators; and 3) provide information and outreach about restoration science to Tribal youth, as well as develop closer working relationships between the Forest Service, the Tribes, and the NGO's.

Methods

The Forest convened the meeting using the North Kaibab Big Springs Ranger Station as a base camp. Following a site visit, participants discussed how and why to conduct rehabilitation. The planning process identified the following work elements: 1) removing the unused and degraded fencing, corrals, and piping (Fig. 6.08); 2) removing graffiti from the backwalls; 3) redirecting flow to support hanging gardens and colluvial slope habitat and constructing an open-water pool beneath the overhang; 4) protecting and restoring flow into the historic ponderosa pine water trough to provide open water for bats, birds and wildlife (Fig. 6.09); 5) fencing the site to protect the resources but provides wildlife access to the overhang; and 6) conducting outreach about this project. Participants discussed removal of nonnative plants and restoring native vegetation, but decided that it should be a secondary restoration step after first focusing on the obvious primary concern of geomorphic rehabilitation. They also agreed that SSI will conduct monitoring, entering survey data into Springs On-

Fig. 6.09: A pipe draws water from the channel to a carved wooden trough. Photo by Molly Joyce © 2015.

Fig. 6.10: Tribal partners helped to remove old corral fencing that was no longer functional.

Fig. 6.11: Before restoration of the site, there were several very small catchments. Seepage emerged from the bedrock walls of coconino sandstone. Species were unable to establish themselves.

Fig. 6.12: After construction of two pools, channel flow and biodiversity increased. Photo by Molly Joyce © 2015.

line so that it will be securely archived and available to collaborators.

In concert with the restoration discussions, the Forest Service staff presented job descriptions about forestry, natural resources management, policy, and law enforcement to the Tribal youth, outlining what educational pathways were needed to work in those topic areas.

Results

Collaborators implemented the plan in July 2014, accomplishing all five planning elements. Participants constructed two fences—a wooden bar fence that allows deer but not cattle to the colluvial slope wetland habitat associated with the springs, and a cyclone wire fence to discourage visitors and livestock from accessing the newly constructed pool beneath the overhang.

Monitoring

SSI monitored Castle Spring in June 2015, a year after the restoration effort. As expected, nonnative herbaceous and graminoid plants colonized the newly exposed surfaces, a process that may resolve as native shrub and tree vegetation takes over naturally, but could be accelerated by translocation planting of selected native shrubs and trees. The inner fencing had been knocked down, perhaps by livestock or hybrid buffalo trying to reach the rock shelter pool; however, this can easily be rebuilt and reinforced. Piles of fence logs that were originally to be burned or removed from the former corral areas are being evaluated as potential bird and small mammal habitat. Surveyors observed a minor amount of new graffiti, suggesting that signage might be appropriate out near the parking area.

Fig. 6.13: Constructed pool and runout channel at Castle Spring in 2015.

Fig. 6.14: A silver-spotted skipper (*Epargyreus clarus*) nectaring on New Mexico honey locust (*Robinia neomexicana*) at Castle Spring. Molly Joyce photo 2015.

Outreach and Education

In addition to the outreach provided by Forest Service staff, the agency brought in a professional film crew to document the work to improve public relations for all collaborators. The resulting Forest Service video on this project is expected to be released shortly.

Challenges

This is an excellent example of collaborative stewardship between the federal government, Native American Tribes and NGOs. The amount and quality of discussion, planning, and actions taken was impressive to all the participants, and is a model that can be followed for the rehabilitation of selected springs everywhere. However, and as with all such efforts, the first 3-5 years following site restoration are not likely to impress visitors: nonnative weeds predominate immediately after the work is completed. The intent of this effort was to limit the amount of maintenance at this remote springs ecosystem, but follow-up monitoring visits and management actions may be required for the first several years after implementation to correct problems that arise unexpectedly. Monitoring wildlife use patterns can help inform managers about further site rehabilitation needs. Signage and outreach may help reduce ongoing vandalism.

Pakoon Spring, Grand Canyon Parashant National Monument

Description/Site Overview

Pakoon Springs is a complex of 10 sources across 22 ha (80 ac) in upper Grand Wash in Grand Canyon-Parashant National Monument, northwestern Arizona. It is one of the largest spring complexes on the Arizona Strip with a total discharge that averages 6.31 L/sec (100 gallons/minute). Prior to its purchase by the Bureau of Land Management (BLM) in 2003, the site was used for a century as a cattle ranch and, for a time, an ostrich farm. With funding from the Arizona Water Protection Fund (AWPF), the BLM partnered with Grand Canyon Wildlands Council (GCWC) to inventory the site in 2000–2001. They subsequently cooperated to assess, plan, restore, and monitor the springs from 2006 to 2012 (Burke et al. 2015).

Partners

Planning engaged agency, non-profit, private, and tribal partners and provided a broad range of options. GCWC used ortho-rectified aerial photography to develop a 0.3 m contour topographic basemap for the entire site (Fig. 6.17). This was used for planning as well as mapping vegetation polygons, soil profiles and sample locations, and hydrologic data collection.

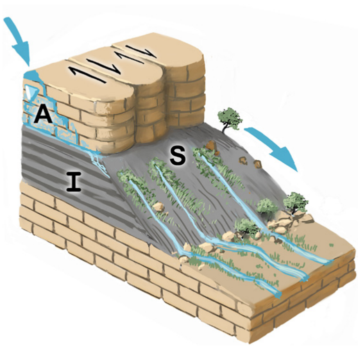
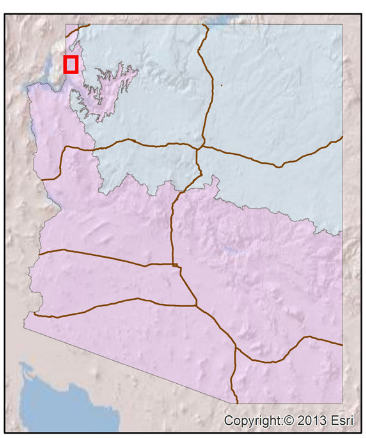


Fig. 6.15: Diagram of a hillslope spring. A=aquifer, S=source, and I=impermeable layer. illustrated by V. Leshyk © 2012).



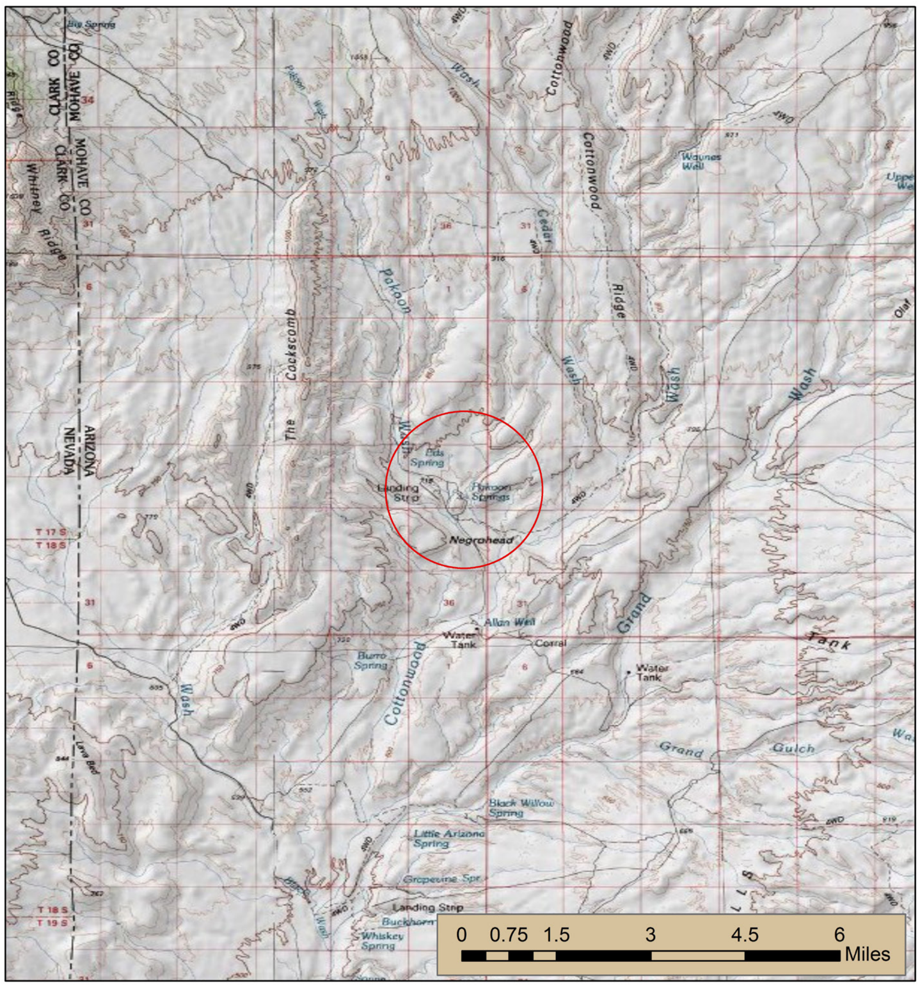


Fig. 6.16: Location of Pakoon Springs in the Grand Canyon Parashant National Monument in Northern Arizona.

Fig. 6.17: GCWCdeveloped this digitally rectified orthophoto contour map of Pakoon Springs prior to rehabilitation efforts. This provided 1-foot contours with a 90% accuracy, generated from a land survey. The GIS products provided the basis for developing hydrologic, vegetation, and planning maps. Map and analysis completed by Chris Brod.

Fig. 6.18: Area identified as Arena 1 of Pakoon Spring in 2007, prior to rehabilitation efforts. GCWC photo.

Methods

GCWC and the BLM began rehabilitation activities in 2007 by removing dozens of truckloads of abandoned equipment and exposed irrigation pipe, many kilometers of fencing, and dilapidated ranch buildings. They also removed nonnative woody plant species (particularly tamarisk – *Tamarix spp*), western mosquitofish (*Gambusia affinis*), American bullfrogs (*Lithobates catesbeianus*), and a remarkably irritable 3 meter long American alligator (*Alligator mississippiensis*) named Clem.

GCWC and BLM rehabilitated geomorphic and vegetation by recontouring excavated water sources and berms and resetting drainages. In these reconstruction efforts, three habitats were of particular interest: wet meadow (ciénega), desert spring-fed stream, and open water.

Results and Monitoring

After replanting local native wetland and riparian vegetation, monitoring results revealed a surprisingly strong recruitment of native plant species. In subsequent surveys, GCWC documented a five-fold increase in riparian vegetation cover over a 3.5 year post-treatment period, and bird species richness totaled nearly two dozen—far more than previously were observed there.

The springs also now support a population of western harvest mouse (*Rheithrodontomys megalotis*). The first phase of the project restored flow in Pakoon Wash, making it the longest perennial desert stream on the 445,159 ha monument. A subsequent AWPF grant supported enhancement of riparian habitat associated with this stream. Bullfrog removal continues in advance of potential translocation wetland species such as leopard frogs.

For more information, see GCWC's final report at http://www.azwpf.gov/Grant_Project_Reports/documents/06-137WPFFinalReport.pdf.

Conclusions

When aquifers have not been damaged or heavily modified, springs ecosystem geomorphology and habitat rehabilitation can be successful. The Pakoon Springs ecosystem was changed from a highly modified and degraded condition to one in which natural ecosystem processes prevail. This project clearly demonstrates that collaborative partnerships focused on clear, well-defined goals and rigorous implementation and monitoring can be used to improve ecosystem function, sustainability, and stewardship, even for highly degraded springs.

Fig. 6.19: Areas identified by GCWC as Arenas 1 and 2 at Pakoon Spring in 2007, prior to rehabilitation efforts. Photo courtesy of GCWC.

Fig. 6.20 Areas identified by GCWC as Arenas 1 and 2 at Pakoon Spring in 2011, following rehabilitation efforts. Photo courtesy of GCWC.

Fig. 6.21 Area identified as Arena 4 at Pakoon Spring in 2013, following rehabilitation efforts. Photo courtesy of GCWC.

Helocrene (Ciénega) Restoration

Ash Spring, Coronado National Forest

Description/Site Overview

Ash Spring is a helocrenic hillslope spring at 1,873 m (6,145 ft) elevation, located in the Chiricahua Mountains of southeastern Arizona. The spring was boxed and, prior to the project, flowed onto a wet meadow less than 2.5 ha (one acre) in size.

Partners

Sky Island Alliance (SIA), Coronado National Forest (Douglas Ranger District), Arizona Game and Fish Department (AGFD), Bat Conservation International, and many volunteers collaboratively restored this site in 2014.

Project Goals and Conservation Targets

The goal of this project was to create new habitat for bats and threatened Chiricahua leopard frog (*Lithobates chiricahuensis*) in the Chiricahua Mountains, where mid- and high-elevation water sources are becoming rare. The Chiricahua Mountains are a large, relatively wet high elevation range

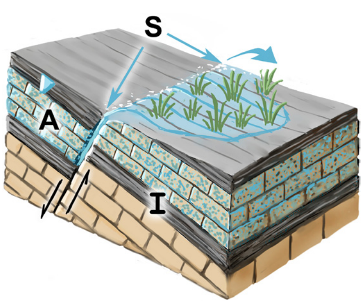
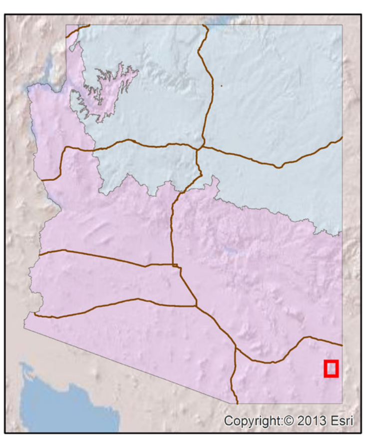


Fig. 6.22: Diagram of a helocrene spring. A=aquifer, S=source, and I=impermeable layer. illustrated by V. Leshyk for SSI © 2012).



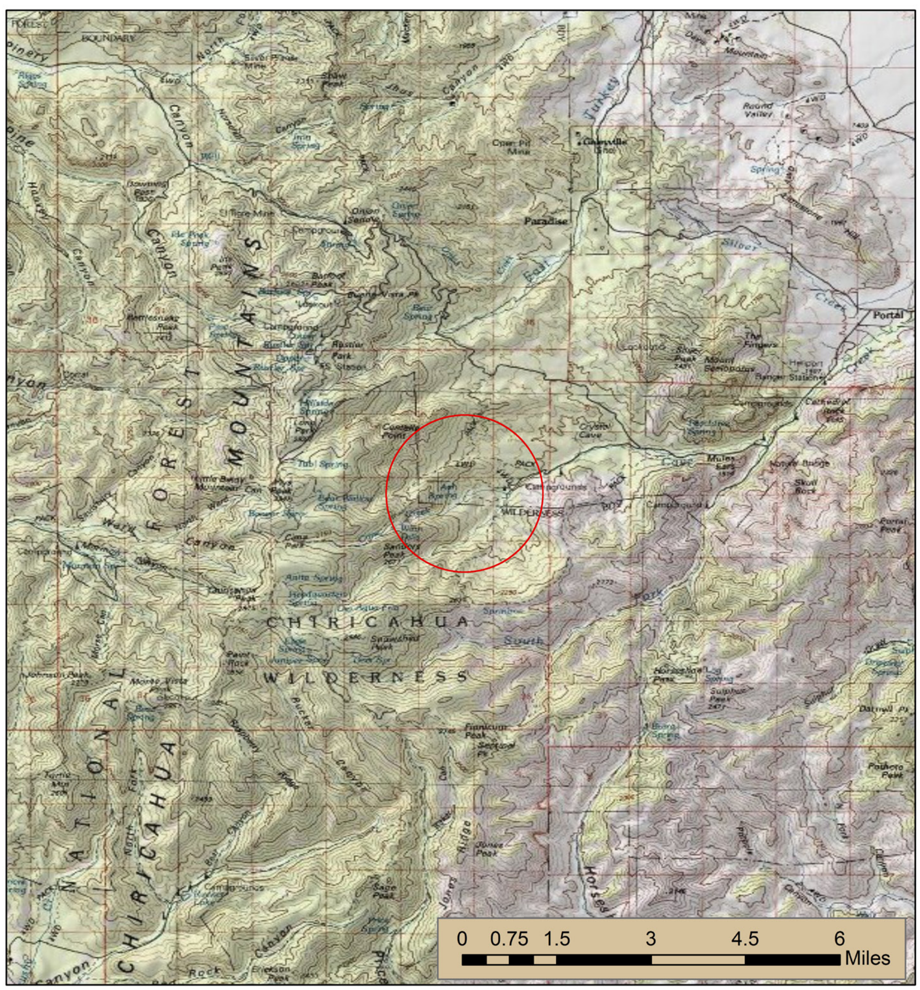


Fig. 6.23: Location of Ash Spring, located in Arizona's Chiricahua Mountains in the Douglas Ranger District of Coronado National Forest.

Fig. 6.24: The restoration team constructed three ponds to provide breeding habitat for Chiricahua laopard frog (*Lithobates chiricahuensis*), and water for bats, pollinators and other wildlife. SIA photo © 2015.

that connects the diverse Sierra Madre with the vast Gila Wilderness—perfectly positioned for importance to a great diversity of plants and animals.

Methods

In May 2014 the restoration team constructed three new ponds using an excavator during a collaborative Wetlands Creation and Restoration Workshop held at the Southwest Research Station in Portal, Arizona. Participants came from four states and various agencies to learn the ropes from wetlands expert, Tom Biebighauser.

The ponds were designed to allow bats to obtain water, provide habitat for Chiricahua leopard frog, and to provide food and cover for pollinators and wildlife. During construction, the crew removed vast amounts of nonnative vegetation and salvaged native grasses, sedges, and herbs (Figs. 6.25 and 6.26). In addition, SIA volunteers installed native plants grown by local native plant nurseries to increase the diversity of flowering species (for nectar resources). Another novel plant material resource came in the form of native grass hay donated by The Nature Conservancy's Aravaipa Canyon Preserve. The team was excited to be able to use this sustainable resource that not only is a source of native grass seeds but also provides erosion control.

Challenges

During construction, the partners decided to alter the original design from nine ponds to three. This decision was made in collaboration with Coronado National Forest and AGFD personnel and addressed concerns to limit the disturbance of the wet meadow habitat, while providing adequate open water resources for bats and Chiricahua leopard frogs. This change prompted lively discussions with workshop participants about how to account for and satisfy multiple ecological goals on a site; in addition, it has stimulated an ongoing discussion among all participating agencies that is helping to frame next steps. Having multiple stakeholders engaged onsite produced invaluable discussion.

Results

Four months after construction, the ponds successfully met habitat creation goals. Sixteen species of bats were documented using the new water

Fig. 6.25: During restoration of Ash Spring, SIA staff, partners and volunteers removed large amounts of horehound, a nonnative species, to be replaced by native vegetation. SIA photo © 2015.

Fig. 6.26: The restoration team salvaged native plant species to be replanted and used plants from local native plant nurseries. SIA photo © 2015.

source during acoustic and mist-net surveys at the end of July, and suspected Chiricahua leopard frog tadpoles were confirmed in early September. SIA also noted that the third and deepest pond was not holding water as expected, presumably because there was not enough clay in the soil to effectively seal the bottom. Working with the Coronado National Forest, SIA is developing a plan to seal the pond so that it is effective winter habitat for leopard frogs, and also to enhance water infiltration in the wet meadow downslope from the pond. The team is seeking grant funding for continuing this project as well as Phase 2 of Ash Spring to reduceerosion in the large gully adjacent to the project.

Monitoring

SIA's Adopt-A-Spring citizen scientist volunteers are monitoring seasonal changes at Ash Spring five times per year, providing a way to keep Coronado National Forest apprised of stewardship needs, and to help maintain this important new water source for wildlife in a sustainable and ecologically functional condition.

Fig. 6.27: Following restoration efforts, constructed fences help protect the wet meadow and ponds from being trampled by livestock. SIA photo © 2015.

Fig. 6.28: (Top) Prior to restoration, Ash Spring was a ciénega (wet meadow) that had been boxed, and had no collection pools. (Bottom) After restoration efforts, the site exhibits improved flow and native vegetation has rebounded. SIA photo © 2015.

Photo by Rich Rudow

Chapter 6
Springs Monitoring

Monitoring is the scientific acquisition and analysis of data to inform stewards about system changes or responses to treatments over time. and is best conducted in relation to clearly defined goals, objectives, and scientific questions. A monitoring plan is a good way to frame the concepts, rationale, and protocols for a Level 3 springs program. Monitoring is one of several potential Level 3 springs stewardship activities that also may include research, rehabilitation planning and implementation, or development. Monitoring should be regarded as a process that will be conducted in perpetuity, so land managers should clearly define and agree upon the commitment, cost, organization, conduct, and information management of the program prior to initiation.

Prior to beginning springs ecosystem monitoring, it also is important to develop and refine the statistical framework for answering the management questions. This will help with development of the monitoring plan by identifying the variables to be measured and frequency of sampling. If a large monitoring program is proposed, we recommend consultation with a trained statistician to ensure the cost-efficiency of the project and the scientific credibility of the results.

What to Monitor

Monitoring should focus on a suite of variables and/or sites that are important to the steward(s), keeping in mind the importance of understanding variation among springs types (sensu Springer and Stevens 2008), cultural and economic values, and ecological integrity. Springs that are being rehabilitated particularly warrant pre-treatment baseline and post-treatment monitoring (Davis et al. 2011).

The Springs Stewardship Institute's Level 2 sampling methods and the SEAP process are appropriate for monitoring habitat area, flow, water quality, site geomorphology, vegetation cover and composition, invertebrate and vertebrate presence, anthropogenic impacts, and administrative context. These methods are generally useful for quantification of springs physical and biological integrity and function, and the extent of human impacts. However, variables like the dynamics of rare populations may be of specific interest in Level 3 projects.

When to Monitor

No single season is best for characterization of all springs variables of interest, and among-season and among-year variation in springs characteristics is likely to be both substantial and necessary for understanding springs ecosystem function (Stevens et al. 2011). Site visits at the height of the growing season (June to September) are needed to characterize vegetation composition and structure and faunal presence, and to minimize variation in seasonal anthropogenic use intensity. However, mid-summer is likely to be the period with the lowest discharge due to seasonally declining water tables and maximum evapotranspiration, creating trade-offs between monitoring flow and biological variables.

Monitoring Plan Elements

Physical Site Monitoring

The initial Level 2 inventory can provide baseline information about geography, hydrogeology, solar radiation budget, and biological characteristics, as well as human impacts and administrative context and uses. However, expansion of detail about these or other variables may be desired for long-term monitoring.

Site Map

It is necessary to develop a close-resolution springs ecosystem map for both rehabilitation and post-treatment monitoring. A high quality map of the study site allows documention of changes in geomorphology and vegetation cover, as well as where sampling measurements are made. Such a map can be developed from aerial photography at 0.3 m or finer scale for determining geomorphic change, planting success, and other such activities.

Microhabitats are relocated during each site visit, and the area of each is measured and re-drawn on the site map. The percent area contribution of each geomorphic habitat type can change between visits, and such changes provide a useful indication of trend in Shannon-Weiner geomorphic habitat diversity. Changes in these variables can identify trends in physical and biological characteristics through time at the springs ecosystem.

Flow Measurement

Systematic hydrological measurements are needed for classifying, understanding, and monitoring spring ecosystems, but flow measurement can be difficult or imprecise. Flow and geochemistry add insight into understanding aquifer mechanics and subterranean flowpath duration. Modeling flow variability requires long-term data: collecting flow data during each site visit is important.

Springs flow may be measured with one or more of the protocols listed in Appendix B. That appendix describes methods to measure springs flow, ranging from the measurement of wetted patch area when flow is unmeasureable, to standard flow capture methods for small springs, the use of portable flumes or weirs for larger springs, and streamflow cross-section velocity measurement.

Such data should be evaluated for quality before being integrated with other physical and bio-cultural information to assess the condition and risks of hydrological alteration to the springs ecosystem (e.g., Wilde 2008).

Flow measurement requires planning, both for the logistics of sampling and the equipment to be used. At the site, flow should be measured at the point of maximum expression, which is not likely to be the source, but rather some distance downstream. The point of flow measurement should be recorded on the site map (above).

Understanding flow variability is important and flow can be expected to vary seasonally in most shallow aquifer or low residence-time aquifers. The most conservative flow measurements are made when, or in settings where transpiration losses and precipitation contributions are minimal (e.g., winter, in bedrock emergence settings). However, it is equally important to understand the impacts of riparian vegetation on water uptake, so mid-summer measurements also are relevant. As stated above, tradeoffs between seasonality and vegetation mean that there is no single time of year that is best for flow measurement. Replicated flow measurements will provide a trustworthy average value and clarify uncertainty within the measurements; we recommend measuring flow at least three times.

If the discharge of the spring is low (zero, unmeasurable, or first magnitude; Appendix B), discharge measurement may take some time and should be started early in the site visit. Second to fifth magnitude discharges are quicker and easier to measure. Measurement of sixth or higher magnitude discharges (non-wadable channels) may require most of the day. Important observations may include the markers of any recent high discharges, such as high water marks, oriented vegetation or debris on or above the channel or floodplain. A novel way to document high flow events is the use of automated oblique photography.

Water Quality Monitoring

Overview

Field and laboratory water geochemistry methods are described by the U.S. Geological Survey (reviewed in Wilde 2008; Appendix B) and recommended by the Environmental Protection Agency. In general, field air and water temperature, pH, specific conductance, total alkalinity, and dissolved oxygen concentration are measured using daily-calibrated field instrumentation. Water quality samples and measurements are made as close to the springs source as possible to capture characteristics of emerging groundwater.

Individual devices (e.g., multimeters) often are designed to measure multiple parameters, but each probe must be calibrated at least daily against laboratory standards. The team hydrologist should record this calibration information in a log book with confirmation on the field data sheet. In our experience, the more expensive the sampling device, the more likely it is to malfunction in remote field settings. Therefore, we recomment several backup devices or strategies for obtaining water quality information.

Filtered 100 mL water quality samples can be collected in triple acid-rinsed bottles for laboratory analyses of major cations and anions and nutrients, if desired. One to two filtered water samples also can be collected in 10 mL acid-washed bottles for stable isotope analyses. Water samples used to test for nitrogen and phosphate concentrations should be promptly delivered to the laboratory for analysis. Water quality samples are stored on ice, but not frozen, following standard sample storage and time-to-analysis protocols.

Geomorphology Monitoring

Geomorphic changes at a site can be qualitatively evaluated using comparative aerial or oblique photography, or by verbal description. However, quantitative documentation of change is prefered. Re-mapping the site at appropriate intervals and documenting changes in microhabitat area and quality are effective techniques. Automatic photograph comparisons also can provide quantitative evidence of change through time.

Biological Monitoring

Vegetation

Level 2 inventory methods are appropriate for documenting vegetation change through time (Chapter 2, Appendix A). The botanist should visually estimate the percent cover of each plant species in seven strata: aquatic, non-vascular (e.g., moss, liverwort), ground (deciduous herbaceous or graminoid), shrub (0-4 m woody perennial), middle canopy (4-10 m woody), tall canopy layers (>10 m woody), and basal cover. Basal cover of woody vegetation is the percent cover of stems

Fig. 6.05: It is important to measure water chemistry as close to the source as possible, and it is best to avoid areas where water is greatly disturbed, such as near a waterfall (shown below). Such areas may cause erroneous measurement of disssolved oxygen and other variables.

(either living or dead) of each dominant woody species emerging on the site. Individual plants may play a role in several canopy layers. For example, tree seedlings (without woody stems) are included in ground cover, whereas saplings fall in shrub cover, and mature trees may contribute to shrub, middle, and tall canopy strata, as well as basal cover.

Several metrics can be calculated from the above data and used for trend assessment. Using the above data, the SSI database auto-calculates plant species density by dividing the number of plant species by the area of the geomorphic microhabitats and that of the entire site. In addition, the database calculates the percent cover and species density of native wetland plant species and non-native plant species in accordance with the USDA-PLANTS database (2013).

Macroinvertebrates

Invertebrates should be collected at each site using spot sampling for a period of at least 30 minutes during the site visit. Spot collection techniques include general collecting, dip-netting, and aerial netting on the site's various microhabitats. Nocturnal site visits often are useful for detecting species that may not otherwise be observed. Nocturnal ultra-violet light trapping also can be used to collect adults of some groups (e.g., caddisflies) that may not otherwise be detected. Seasonal nocturnal and ultraviolet sampling should be considered for the first several years of monitoring to establish the range of natural variation and, if warranted, at 3-5 year intervals thereafter to check on macroinvertebrate species composition.

Quantitative benthic macroinvertebate sampling can be used for monitoring if flows are sufficient to provide either deep pool habitats, or channels have flow more than 1.5 cm deep. Benthic invertebrates can be quantitatively sampled using standardized time- and area-based methods. A Surber or mini-Surber sampler, kicknet (either 1.0 m or 0.25 m wide net), Hess or mini-Hess sampler, or aquarium or D-net can be used to sample benthic invertebrates by placing the device at a randomly selected position in the stream, vigorously disturbing a known area (usually 0.09 m^2) for one minute, and allowing the water with invertebrates to flow into the net. The net meshing should be sufficiently fine to capture macroinvertebrates (0.2 to 0.5 mm diameter). Percent cover of substrata, depth, and velocity should be noted at each site, as well as the site's field water quality variations (temperature, pH, specific conductance, and dissolved oxygen concentration). Three or more benthic sample replicates should be collected in 70% EtOH, each in a separate 0.5 L sample bottle, and returned to the laboratory for enumeration and taxonomic analysis. If funding is insufficient for such laboratory enumeration and identification costs, rapid enumeration and identification can be accomplished in the field. Specimens of unrecognized species should be collected for taxonomic analysis.

Many useful indices have been developed for assessing relationships between water quality and macroinvertebrates (Merritt et al. 2008). Among those most often used is the EPT index, calculated by summing the number of mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera) in standardized benthic samples (Barbour et al. 1999, Merritt et al. 2008). Most species in those orders require high quality water, and thus are good indicators of impairment. However, ion-rich waters are often natural in Arizona and such waters do not support high levels of EPT. In such cases, other (particularly rare or endemic) invertebrates may be better indicators of water quality impairment.

Vertebrates

The survey crew should record presence, signs, or sounds of vertebrate species detected during monitoring. Long-term monitoring will eventually contribute to a list of vertebrate use of the site. However, if more detailed information is needed, motion-activated cameras, trapping, and a more intensive site visit schedule can be employed.

Special Monitoring Elements

Once a complete inventory of the springs types, species, and conditions at the springs in a landscape have been conducted, decisions can be made about more detailed monitoring of special features (e.g., particular landforms, hydrological variables, species, or ecological processes). The population dynamics of various taxa can be monitored more closely, and are best studied in relation to specific population- or habitat-based questions. For aquatic vegetation and water quality, thin slice analysis of travertine may provide insight into diatom composition in relation to water quality over time. For wetland and terrestrial vegetation, long-term transects may provide more detailed information that can be more accurately compared over time, and studies of the number, condition, and growth of individual sensitive plant species can be planned and undertaken. For trees, dendrochronological analyses may provide retrospective trend data on growth and perhaps flow and water quality (e.g., http://web.utk.edu/~grissino/index.htm).

The size and/or condition of sensitive invertebrate populations is often monitored using the standardized benthic sampling methods (above), or quantification of numbers of individuals/unit area/sampling duration over the life cycle of the target species (Merritt et al. 2008). For example, Martinez and Thome (2006) used quantitative monitoring to determine population dynamics and the life history of the endemic Page springsnail (*Pyrgulopsis morrisoni*) in central Arizona.

Monitoring of vertebrates at springs should be conducted systematically, and trends over time can be determined. Fish monitoring usually involves indirect sampling intensity-based capture per unit effort (CPUE) methods or direct density estimation using seining, backpack-electroshocking, snorkeling, or SCUBA. Amphibian and other herpetofaunal surveys and monitoring are most efficiently conducted using non-lethal "light-touch" visual surveys, in which surveyors gently explore suitable habitats, turning over and replacing logs, rocks, or artificially-installed habitats (e.g., plywood boards). In addition, they may use temporary pit-fall traps to locate or capture herpetofaunae (O'Donnell et al. 2007). Point-count methods are standard for avian monitoring (US Fish and Wildlife Service 1999: http://www.fws.gov/mountain-prairie/migbirds/avian_monitoring.pdf). Live trap sampling population assessment, and disease vector monitoring methods have been developed for small mammals (e.g., https://clu-in.org/download/ert/2029-R00.pdf). Genetics sampling methods also are sometimes used to evaluate population viability of vertebrates, using samples of blood or tissue from animals that are collected, or from hair or feces collected randomly or along transects (https://en.wikipedia.org/wiki/Genetic_monitoring#Estimating_abundance_and_life_history_parameters_.E2.80.93_Category_Ia.).

Equipment Sterilization

On leaving the monitoring site, surveyors should sterilize shoes, nets and other items to prevent spread of chitrid fungus, other disease microorganisms, and nonnative species. Appropriate sterilization methods for clothing, equipment, and vehicles are found at: http://www.issg.org/database/species/reference_files/batden/man.pdf. That website reported that "the most effective products for [sterilizing field equipment and clothing to prevent chitrid fungus dispersal] were Path-XTM and the quaternary ammonium Compound 128, which can be used at dilutions containing low levels of the active compound didecyl dimethyl ammonium chloride. Bleach, containing the active ingredient sodium hypochlorite, was effective at concentrations of 1% sodium hypochlorite and above. Didecyl dimethyl ammonium chloride at a concentration greater than 0.0012% for 2 min, or sodium hypochlorite at a concentration greater than 1% for 1 min are effective treatment procedures." However, high concentrations of sterilization fluids also pose a threat to springs biota, so we also recommend post-sterilization rinsing with clean water (see Chapter 2).

Information Management

All data, photographs, the sketchmap, and other information about the biology of each variable and the overall springs ecosystem monitored should be entered into a relational database. SSI's Springs Online database at http://springsdata.org/ provides a free, online, secure, easy-to-use, and comprehensive springs information management system).

Quality control analyses of data entered into such a system should be conducted using standard methods (Ledbetter et al. 2012, described at: http://springstewardshipinstitute.org/). A well-designed database, such as Springs Online, must be designed not only to archive monitoring data, but also to produce automated reports on the condition and trends through time of focal variables. Such database capacity vastly simplifies regular reporting and conserves staff time.

Physical and biological specimens require preparation, identification, databasing, and curatio, and should be archived in professional museum collections.

Improving Stewardship

The purpose of a monitoring program is to assess and improve resource stewardship (Fig. 4.01). Depending on the scope of the management plan, the monitoring data will contribute to stewardship of individual resources, individual springs, or multiple springs across a landscape. Regular and consistent review of monitoring results will help the stewardship team understand project success and challenges. This feedback will help clarify developing changes in resource dynamics and the necessary next steps towards improving stewardship.

Appendix A

Field Forms and SEAP Criteria

The following pages contain field forms and SEAP criteria in use by SSI and SIA as of January 2016. These match the Springs Online database, making data entry very straightforward. As the protocols and field sheets are refined based on peer review, feedback from partners, and field testing, they are occasionally modified. The most up-to-date forms, SEAP criteria, and inventory protocols are available for download as PDFs at: http://springstewardshipinstitute.org/downloadsandpdfs/.

The Springs Online database is available at http://springsdata.org/, and the manual, with images and instructional videos are online at http://springstewardshipinstitute.org/database-manual-1.

A username and password are required to access information; simply set up an account. This will allow access to publicly-available location data for any of the springs in the database. However, permissions are required to access survey data. Contact an administrator of the land unit for permission to access information. For more information, or if you are a land unit administrator, please contact springsdata@musnaz.org.

General

Spring Name___________________________________ [1]Spring Type _______________________

Country____ State_______ County_________________________ [2]Sensitivity _________

[3]Land Unit____________ Land Unit Detail__________________________________

Quad_____________________ HUC___________________________

Site Description

Georef

[4]Georef Source__________ Device_________________________ Datum_________

UTM Zone_______ UTM East_________________ UTM North_____________

Lat___________________Long__________________ Elev_________ ft or m

EPE______ ft or m Declination _____ Comment _____________________________

Access Directions

SPF

Sunrise: D_______ J_______ N_______ F_______ O_______ M_______ S_______ A_______ A_______ M_______ J_______ J_______

Sunset: D_______ J_______ N_______ F_______ O_______ M_______ S_______ A_______ A_______ M_______ J_______ J_______

Survey

Date________________ Begin Time_____________ End Time______________

Surveyors____

____Project_________________

Site Condition

Microhabitats

	Description	Area (m²)	[5]Surf Type	[6]Sub-Type	[7]Slope Var	Aspect T/M___	Slope Deg	[8]Soil moist	Water dpth(cm)	Water %	[9]Substrate % 1	2	3	4	5	6	7	8	Org	Oth	Prec %	Litter %	Wood %	Litter (cm)
A																								
B																								
C																								
D																								
E																								
F																								
G																								

Images

Camera Used____

Sketch Map Location___________________________________

Photo #	Description

Entered by ______________________________ Date________ Checked by ______________ Date ________

1 Discharge Sphere (Spring Type)
- Anthropogenic
- Cave
- Exposure
- Fountain
- Geyser
- Gushet
- Hanging Garden
- Helocrene
- Hillslope
- Hypocrene
- Limnocrene
- Mound-form
- Rheocrene

2 Sensitivity
- None
- Location
- Survey
- Both

3 Land Unit
- BLM
- DOE
- NPS
- Private
- State
- Tribal
- USFS
- Other

4 Georeference Source
- GPS
- Map
- Other

5 Surface Type
- BW Backwall
- C Cave/Tunnel
- CH Channel
- CS Colluvial slope
- HGC High Grad. Cienega
- LGC Low Grad Cienega
- Mad Madiculous Flow
- O Organic Ooze
- P Pool
- PM Pool Margin
- SB Sloping Bedrock
- SZ Spray Zone
- SM Spring Mound
- TE Terrace
- Upl Adjacent Uplands
- WH Wet Hillslope
- Oth Other

6 Surface Subtype
- CH Riffle, Run, Margin, Eph
- TE LRZ, MRZ, URZ, HRZ UPL,LRZMRZ,LRZURZ, MRZURZ, HRZMRZ
- All Anthro

7 Slope Variability
- Low, Medium, High

8 Soil Moisture
- 0 - Dry
- 1 - Dry-Moist
- 2- Moist-Dry
- 3 - Wet-Dry
- 4- Moist
- 5 - Saturated-Dry
- 6 - Wet
- 7 - Saturated-Moist
- 8 - Wet-Saturated
- 9 - Saturated
- 10 - Inundated

9 Substrate
- 1 clay
- 2 silt
- 3 sand
- 4 fine gravel
- 5 coarse gravel
- 6 cobble
- 7 boulder
- 8 bedrock
- Organic Soil
- Other/anthropogenic

10 Lifestage
- Adult
- Egg
- Exuviae
- Immature
- Larvae
- Mixed
- Other
- Pupae
- Shell

11 Habitat
- AQ - Aquatic
- T - Terrestrial

12 Method (Invertebrates)
- Spot
- Benthic

13 Detection Type (Vertebrates)
- Call
- Observed
- Sign
- Reported (by others)
- Other

14 Cover Codes
- GC Ground Cover
- SC Shrub Cover
- MC Midcanopy Cover
- TC Tall Canopy Cover
- AQ Aquatic Cover
- NV Nonvascular (moss, etc)
- BC Basal Cover

15 Emergence Environ/Detail
- Cave
- Subaerial
- Subglacial
- Subaqueous-lentic freshwater
- Subaqueous-lotic freshwater
- Subaqueous-estuarine
- Subaqueous-marine

16 Source Geomorphology
- Contact Spring
- Fracture Spring
- Seepage or filtration
- Tubular Spring

17 Flow Force Mechanism
- Anthropogenic
- Artesian
- Geothermal
- Gravity
- Other

18/19 Parent Rock Type/Subtype
- Igneous
  - andesite
  - basalt
  - dacite
  - diorite
  - gabbro
  - grandodiorite
  - granite
  - peridotite
  - rhyolite
- Metamorphic
  - gneiss
  - marble
  - quartzite
  - slate
  - schist
- Sedimentary
  - coal
  - conglomerate
  - dolomite
  - evaporates
  - limestone
  - mudstone
  - sandstone
  - shale
  - siltstone
  - Unconsolidated

20 Channel Dynamics
- Mixed runoff/spring dominated
- Runoff dominated
- Spring dominated
- Subaqueous

21 Flow Consistency
- Dry intermittent
- Erratic intermittent
- Perennial
- Regular intermittent

22 Measurement Technique
- Current meter
- Weir
- Cutthroat flume
- Other

Spring Name________________________ Page ______ of _________ OBS____________

Inverebrates

Species Name	Qty	[10]Stage	[11]Hab-itat	[12]Meth-od	Rep #	Comments

Benthic Rep

Rep #	Location	Velocity m/sec	Depth cm	Substrate	Area Sq M	Time Sec	Comments

Entered by ______________________ Date__________ Checked by ______________________ Date ___________

Vertebrates

Spring Name____________________ Page _____ of ______ OBS________

Species Name	No. Ind	[13]Detection Type	Comments

Entered by ________________ Date________ Checked by ________________ Date ________

Spring Name__________________________ Page ______ of _________ OBS ____________

Flora

Species Name	[14]Str	A	B	C	D	E	F	G	H	Comments	No. Ind	No. Coll

Entered by ___________________________ Date___________ Checked by __________________________ Date ______________

Spring Name__________________________ Page ______ of _________ OBS____________

Flora

Species Name	^{14}Str	A	B	C	D	E	F	G	H	Comments	No. Ind	No. Coll

Entered by __________________________ Date___________ Checked by ___________________________ Date ______________

Spring Name________________________ Page ______ of _________ OBS____________

Geomorphology

[15]Emerg Env________________________ [17]Mechanism________________________ Geologic Layer______________________

[15]Detail____________________________ [18]Rock Type_________________________ [20]Channel Dynamics___________________

[16]Source Geo________________________ [19]Rock Subtype______________________

Polygon	[1]Discharge Sphere	[1]Secondary Discharge	Comments

Water Quantity

[21]Flow Consistency___________________ [22]Measurement Technique______________________ Flow Rate (Mean)____________________________

Location of Measurements____Total Site % Captured___________________________

Discharge Comments____

Current Meter l/s m/s other_____

Cell	Distance	Width	Depth	Reading

Flume l/s m/s other_____

Point	Flume Size	Measurements					Avg Stage	% Flow

Volume

Container Size/Units___________

Point	Volume	Time to Fill	% Flow

Weir l/s m/s other_____

Point	Weir Size	Measurements				% Flow

Entered by ________________________________ Date____________ Checked by _________________________ Date ______________

Spring Name____________________ Page ______ of _________ OBS____________

Water Quality

Measurement Device(s)______________________________ Date Last Calibrated______________ Air Temp ___________

Collection Location/Comments____

____

Field Measurements

Depth (cm)	pH	Conductivity	Dissolved O^2	Water Temp. (°C)	Turbidity	Alkalinity	Other	Device
Average								

Collected for Analysis

Sample Type	Sample Taken?	DuplicateTaken?	Container	Filtered (Y/N)	Treatment	
Anions						
Cations						
Nutrients						
^{2}H and ^{18}O Isotopes						

Entered by ____________________________ Date__________ Checked by ________________________ Date ____________

SEAP

Spring Name ______________________ Date ______________ Page ____ of ____Obs________

Information Source ____

Aquifer/WQ	Cond	Risk	Habitat	Cond	Risk	Human Influence	Cond	Risk	Administrative Context	Cond	Risk
Spring dewatered (Y/N)			Isolation			Surface water quality			Information quality/quantity		
Aquifer functionality			Habitat patch size			Flow regulation			Cultural significance		
Spring discharge			Microhabitat quality			Road/trail/railroad			Historical significance		
Flow naturalness			Native plant ecological role			Fencing			Recreational significance		
Flow persistance			Trophic dynamics			Construction			Economic value		
Water quality			**Score**			Herbivory			Conformance to mgmt plan		
Algal and periphyton cover			**Biotic Integrity**			Recreational			Scientific/educational value		
			Native plant richness/diversity			Adjacent conditions			Environmental compliance		
Geomorpology			Native faunal diversity			Fire influence			Legal status		
Site obliterated (Y/N)			Sensitive plant richness								
Geomorphic functionality			Sensitive faunal richness								
Runout channel Geometry			Nonnative plant rarity								
Soil integrity			Nonnative faunal rarity								
Geomorphic diversity			Native plant demography								
Natural physical disturbance			Native faunal demography								

Notes:

Recommendations:

Entered by ______________________ Date__________ Checked by ______________________ Date ____________

Site______________________ Date__________ Info Source______________

Springs Ecosystem Assessment Protocol Scoring Criteria

Aquifer and Water Quality

AFWQ0 Springs Dewatered (Y/N)

AFWQ1 Aquifer functionality

- 0 Aquifer depleted
- 1 Aquifer nearly depleted
- 2 Aquifer in significant decline
- 3 Aquifer declining slightly but detectably
- 4 Low to moderate aquifer withdrawal
- 5 Aquifer not or only very slightly pumped
- 6 Aquifer pristine; good potential reference site
- 9 Unable to assess aquifer functionality

AFWQ2 Springs discharge

- 0 No flow
- 1 Less than .1 liters per second
- 2 Between .1 and 1 liters per second
- 3 Between 1 and 10 liters per second
- 4 Between 10 and 100 liters per second
- 5 Between 100 and 1000 liters per second
- 6 Over 1000 liters per second
- 9 Unable to assess flow

AFWQ3 Flow naturalness

- 0 Springs dewatered
- 1 Springs mostly dewatered
- 2 Springs flow strongly reduced
- 3 Springs flow slightly, but distinctively, reduced
- 4 Springs flow only slightly reduced
- 5 Springs flow apparently natural
- 6 Springs pristine; good potential reference site
- 9 Unable to assess flow naturalness

AFWQ4Flow persistence

- 0 No springs flow
- 1 Flow ephemeral, less than 50% of time
- 2 Flow rarely ephemeral
- 3 Flow recently persistent
- 4 Flow apparent during Holocene
- 5 Flow continuous since late Pleistocene
- 6 Flow since mid-Pleistocene or earlier
- 9 Unable to assess flow persistence

AFWQ5Water quality

- 0 No water
- 1 Water quality less than 10% of natural condition
- 2 Water quality 10 to 30% of natural condition
- 3 Water quality 30 to 60% of natural condition
- 4 Water quality 60 to 90% of natural condition
- 5 Water quality 90 to 99% of natural condition
- 6 Water quality fully natural
- 9 Unable to assess water quality

AFWQ6 Algal and periphyton cover

- 0 Algal or periphyton cover wholly unnatural
- 1 Natural cover of algae or periphyton very poor
- 2 Natural cover of algae or periphyton poor
- 3 Natural cover of algae or periphyton moderate
- 4 Natural cover of algae or periphyton good
- 5 Natural cover of algae or periphyton very good
- 6 Cover of algae or periphyton wholly natural
- 9 Unable to assess algal and periphyton cover

Geomorphology

GEO1 Geomorphic functionality

- 0 Site obliterated unnaturally
- 1 <25% original natural microhabitat types remain
- 2 25-50% of natural microhabitat types remain
- 3 50-75% of natural microhabitat types remain
- 4 75-90% of natural microhabitat types remain
- 5 90-98% of natural microhabitat types remain
- 6 Natural microhabitat types pristine
- 9 Unable to geomorphic functionality

GEO2 Runout channel geometry

- 0 Original runout channel unnaturally obliterated
- 1 Channel virtually obliterated, trenched, or otherwise manipulated
- 2 Channel strongly altered, with only scant evidence of original course
- 3 Channel highly altered but with some functionality
- 4 Channel slightly altered, mostly functional
- 5 Channel functioning apparently naturally
- 6 Channel pristine
- 9 Unable to assess channel geometry

GEO3 Soil integrity

- 0 Natural soils eliminated
- 1 Virtually all natural soils eliminated
- 2 Soils thin or eliminated on most of site but a detectable amount remaining
- 3 Soils patchy and compromised, with degraded functionality
- 4 Soils large intact, and only slightly compromised
- 5 Soils apparently natural, with very minor reduction in functionality
- 6 Soils fully natural
- 9 Unable to assess soil integrity

GEO4 Geomorphic diversity

- 0 None; a completely unnatural condition
- 1 Very low geomorphic diversity
- 2 Low geomorphic diversity
- 3 Moderate geomorphic diversity
- 4 Good geomorphic diversity
- 5 Very good geomorphic diversity
- 6 Pristine; fully natural geomorphic diversity
- 9 Unable to assess geomorphic diversity

GEO5 Natural physical disturbance

- 0 Natural disturbance regime obliterated
- 1 Natural disturbance regime virtually eliminated
- 2 Highly altered natural disturbance regime
- 3 Moderately altered natural disturbance regime
- 4 Little altered natural disturbance regime
- 5 Nearly natural disturbance regime
- 6 Natural disturbance regime virtually pristine
- 9 Unable to assess natural disturbance regime

Site________________________________ Date______________

Habitat

HAB1 Isolation

0 <10 m from the nearest springs ecosystem
1 10-50 m from the nearest springs ecosystem
2 50-100 m from the nearest springs ecosystem
3 100-500 m from the nearest springs ecosystem
4 500-1000 m from the nearest springs ecosystem
5 1-10 km from the nearest springs ecosystem
6 >10 km from the nearest springs ecosystem
9 Unknown distance to nearest springs ecosystem

HAB2 Habitat patch size

0 No springs habitat area
1 < 10 sq m habitat area
2 10 - 100 sq m habitat area
3 100-1000 sq m habitat area
4 .1 - 1 hectare habitat area
5 1 - 10 hectare habitat area
6 >10 hectare habitat area
9 Unable to assess habitat area

HAB3 Microhabitat quality

0 No microhabitats exist or remain
1 Very low microhabitat quality
2 Low microhabitat quality
3 Moderate microhabitat quality
4 Good microhabitat quality with some indication of impairment
5 Very good microhabitat quality, but past impairment suspected
6 Pristine microhabitat quality
9 Unable to assess microhabitat impairment

HAB4 Native plant ecological role

0 No native plant species present
1 Native species cover and biomass <25% of natural condition
2 Native species cover and biomass 25-50% of natural condition
3 Native species cover and biomass 50-75% of natural condition
4 Native species cover and biomass 75-90% of natural condition
5 Native species cover and biomass 90-98% of natural condition
6 Native species cover and biomass virtually pristine
9 Unable to assess native plant species ecological role

HAB5 Trophic dynamics

0 No trophic dynamics occurring
1 Trophic dynamics and ecological efficiency scarcely extant (<25%)
2 Trophic dynamics and ecological efficiency poor (25-50%)
3 Trophic dynamics and ecological efficiency moderate (50-75%)
4 Trophic dynamics and ecological efficiency fair (75-90%)
5 Trophic dynamics and ecological efficiency good (90-98%)
6 Trophic dynamics and ecological efficiency pristine (>98%)
9 Unable to assess trophic dynamics and ecological efficiency

Biolota

BIO1a Native plant richness and diversity

0 No native plant species remaining
1 <25% of expected species remaining
2 25-50% of expected species remaining
3 50-75% of expected species remaining
4 75-90% of expected species remaining
5 90-98% of expected species remaining
6 >98% of expected species remaining
9 Unable to assess native vascular plant richness and diversity

BIO1b Native faunal diversity

0 No expected species remaining
1 <25% of expected species remaining
2 25-50% of expected species remaining
3 50-75% of expected species remaining
4 75-90% of expected species remaining
5 90-98% of expected species remaining
6 >98% of expected species remaining
9 Unable to assess native faunal diversity

BIO2a Sensitive plant richness

0 No sensitive or listed plant species remain
1 <25% of expected species remaining
2 25-50% of expected species remaining
3 50-75% of expected species remaining
4 75-90% of expected species remaining
5 90-98% of expected species remaining
6 >98% of expected species remaining
9 Unable to assess native sensitive vascular plant species

BIO2b Sensitive faunal richness

0 No sensitive or listed faunal species remain
1 <25% of expected species remaining
2 25-50% of expected species remaining
3 50-75% of expected species remaining
4 75-90% of expected species remaining
5 90-98% of expected species remaining
6 >98 of expected species remaining
9 Unable to assess native sensitive faunal species

BIO3a Nonnative plant rarity

0 >75% of plant species are non-native
1 50-75% of plant species are non-native
2 25-50% of plant species are non-native
3 10-25% of plant species are non-native
4 5-10% of plant species are non-native
5 2-5% of plant species are non-native
6 <2% of plant species are non-native
9 Unable to assess nonnative plant species rarity

BIO3b Nonnative faunal rarity

0 >75% of faunal species are non-native
1 50-75% of faunal species are non-native
2 25-50% of faunal species are non-native
3 10-25% of faunal species are non-native
4 5-10% of faunal species are non-native
5 2-5% of the faunal species are non-native
6 <2% of faunal species are non-native
9 Unable to assess nonnative faunal species rarity

Site______________________________ Date_____________

BIO4a Native plant demography

- 0 No native plant populations remain
- 1 <25% of dominant native plant populations present and self-sustaining
- 2 25-50% of dominant native plant populations present and self-sustaining
- 3 50-75% of dominant native plant populations present and self-sustaining
- 4 75-90% of dominant native plant populations present and self-sustaining
- 5 90-98% of dominant native plant populations present and self-sustaining
- 6 Dominant native plant populations self-sustaining in a natural condition
- 9 Unable to assess native vascular plant population demography

BIO4b Native faunal demography

- 0 No natural faunal populations remain
- 1 <25% of native faunal populations present and self-sustaining
- 2 25-50% of native faunal populations present and self-sustaining
- 3 50-75% of native faunal populations present and self-sustaining
- 4 75-90% of native faunal populations present and self-sustaining
- 5 90-98% of native faunal populations present and self-sustaining
- 6 Native faunal populations self-sustaining in a natural condition
- 9 Unable to assess native faunal population demography

Freedom from Human Influences

FHI1 Surface water quality

- 0 No flow
- 1 Very poor surface water quality
- 2 Poor surface water quality
- 3 Moderate surface water quality
- 4 Good surface water quality
- 5 Very good surface water quality
- 6 Excellent surface water quality
- 9 Unable to assess desired surface water quality

FHI2 Flow regulation

- 0 Flow regulation influences have eliminated or destroyed the springs
- 1 Very extensive flow regulation influences
- 2 Extensive flow regulation influences
- 3 Moderate flow regulation influences
- 4 Limited flow regulation influences
- 5 Very limited flow regulation influences
- 6 No flow regulation effects
- 9 Unable to assess flow regulation influences

FHI3 Road, Trail, and Railroad effects

- 0 Road, trail, or railroad influences have eliminated the springs
- 1 Very extensive road, trail, or railroad influences
- 2 Extensive road, trail, or railroad influences
- 3 Moderate road, trail, or railroad influences
- 4 Limited road, trail, or railroad influences
- 5 Very limited road, trail, or railroad influences
- 6 No road, trail, or railroad influences
- 9 Unable to assess road, trail, or railroad influences

FHI4 Fencing effects

- 0 Negative influences of fencing have eliminated the springs
- 1 Very extensive negative influences of fencing
- 2 Extensive negative influences of fencing
- 3 Moderate negative influences of fencing
- 4 Limited negative influences of fencing
- 5 Very limited negative influences of fencing
- 6 No negative influences of fencing
- 9 Unable to assess influences of fencing

FHI5 Construction effects

- 0 Construction influences eliminated the springs
- 1 Very extensive negative construction influences
- 2 Extensive negative construction influences
- 3 Moderate negative construction influences
- 4 Limited negative construction influences
- 5 Very limited negative construction influences
- 6 No negative construction influences
- 9 Unable to assess construction influences

FHI6 Herbivore effects

- 0 Herbivory influences have eliminated the springs
- 1 Very extensive negative herbivory influences
- 2 Extensive negative herbivory influences
- 3 Moderate negative herbivory influences
- 4 Limited negative herbivory influences
- 5 Very limited negative herbivory influences
- 6 No negative herbivory influences
- 9 Unable to assess herbivory influences

FHI7 Recreational effects

- 0 Recreation influences have eliminated the springs
- 1 Very extensive negative recreational influences
- 2 Extensive negative recreational influences
- 3 Moderate negative recreational influences
- 4 Limited negative recreational influences
- 5 Very limited negative recreational influences
- 6 No negative recreational influences
- 9 Unable to assess recreational influences

FHI8 Adjacent lands condition

- 0 Ecological condition of adjacent landscape has eliminated the springs
- 1 Very extensive negative influences of adjacent landscape
- 2 Extensive negative influences of adjacent landscape
- 3 Moderate negative influences of adjacent landscape
- 4 Limited negative influences of adjacent landscape
- 5 Very limited negative influences of adjacent landscape
- 6 No negative influences of adjacent landscape
- 9 Unable to assess influences of adjacent landscape

Site______________________________ Date_____________

FHI9 Fire Influence

0 Fire influences have eliminated the springs
1 Very extensive negative influences of fire
2 Extensive negative influences of fire
3 Moderate negative influences of fire
4 Limited negative influences of fire
5 Very limited negative influences of fire
6 No undesired negative influences of fire
9 Unable to assess influences of fire

Administrative Context

AC1 Information quality/quantity

0 No information or map exists
1 Very limited mapping or other information
2 Limited mapping or other information exists
3 A modest amount of credible mapping and other information exists
4 Credible mapping and other scientific information exists
5 A great deal of high quality mapping and other information has been gathered and compiled
6 The springs is used as a research site, with much high quality information available
9 Unable to assess information quantity and quality

AC2 Indigenous significance

0 No significance as an indigenous cultural site
1 Virtually no evidence of indigenous cultural features or resources
2 One culturally significant feature or resource
3 Two or more culturally significant features or resources
4 Several culturally significant features or resources
5 Numerous indigenous culturally significant features or resources
6 Cultural significance essential for the well-being of one or more indigenous cultures
9 Unable to assess indigenous cultural significance

AC3 Historical significance

0 No historical significance
1 Very little evidence of historically significant elements
2 One historically significant element
3 Two or more historically significant elements
4 Several historically significant elements
5 Numerous historically significant elements
6 Historical significance essential for the well-being of the culture
9 Unable to assess historical significance

AC4 Recreational significance

0 Desired effects of recreational use not achieved
1 Very extensive deviation from desired effects of recreational use
2 Extensive deviation from desired effects of recreational use
3 Moderate deviation from desired effects of recreational use
4 Limited deviation from desired effects of recreational use
5 Very limited deviation from desired effects of recreational use
6 No deviation from desired effects of recreational use
9 Unable to assess deviation from desired effects of recreational use

AC5 Economic value

0 The springs has no economic value
1 Very limited economic value
2 Limited economic value
3 Modest economic value
4 Considerable economic value
5 High economic value
6 Very high economic value
9 Unable to assess economic value

AC6 Conformance to mgmt plan

0 No management plan
1 Minimal management planning
2 Very preliminary management plan
3 Management plan exists, but receives little management attention
4 Management plan given moderate attention
5 Management plan given substantial management & legal consideration
6 Management plan fully implemented and followed
9 Unable to assess conformance to management plan

AC7 Scientific/educational value

0 No features of scientific or educational interest
1 One scientifically or educationally important feature
2 Two features of scientific or educational interest
3 Several features of scientific or educational interest
4 4-9 features of scientific or educational interest
5 At least 10 features of scientific or educational interest
6 Numerous features of scientific or educational interest
9 Unable to assess scientific or educational significance

AC8 Environmental compliance

0 No socioenvironmental compliance conducted or considered
1 Very little socioenvironmental compliance conducted or considered
2 Little socioenvironmental compliance conducted or considered
3 Preliminary socioenvironmental compliance conducted
4 Socioenvironmental compliance undertaken, not yet completed
5 Socioenvironmental compliance completed, not enacted
6 Environmental compliance, and designation of critical habitat, is complete
9 Unable to assess environmental compliance

AC9 Legal status

0 No land, water, or ecosystem legal rights exist or are recognized

Site______________________________ Date_____________

1 Rights may exist but have not been adjudicated or enforced
2 Rights exist but application for those rights/ uses are pending; no enforcement
3 Rights exist and applications have been made; limited enforcement
4 Rights applications have been completed; moderately robust enforcement
5 Rights have been established; robust enforcement
6 Rights established and defended; legislative protection; robust enforcement
9 Unable to assess legal status

Risk

0 No risk to site
1 Negligible risk to site
2 Low risk to site
3 Moderate risk to site
4 Serious risk to site
5 Very great risk to site
6 Extreme risk to site
9 Unable to assess risk to site

Site______________________________ Date______________________

Information Source______________________________ Cultural Radius (meters)______________

Cultural Values

Archaeological Value

0 No archaeological evidence present at or near spring
1 Almost no evidence of archeological remains near the spring
2 Minor evidence of archaeological artifacts near the spring (i.e., ceramics)
3 Moderate evidence of archaeological remains near the springs; hunting camp remains, potentially including hearth(s) but no dwellings evident
4 Artifacts, petroglyphs, minor ruins, and/or irrigation works are present, demonstrating fairly extensive prehistoric use of the site
5 Artifacts, petroglyphs, ruins, and/or water works, and dwelling sites are present, demonstrating extensive prehistoric use
6 Artifacts, petroglyphs, remains, and extensive ruins nearby, protected by the tribe due to great archaeological significance
9 Unable to assess archaeological value

Petroglyphs
Shrines
Walls
Jewelry
Ceramics
Flakes
Hearths
Ruins
Irrigation
Middens
Agriculture
Human Remains
Historical Archaeology
Other archaeology

Education/Knowledge Value

0 No knowledge of the site recorded in tribal history or academic records, and no information reasonably expected to exist
1 Knowledge of site expected to exist, but not available, no longer taught
2 Knowledge of site is documented but is minimal and not used in education or research
3 Moderate knowledge of site exists; is used to a moderate extent in education and/or as a research site
4 Fairly significant education and/or research significance
5 Very good educational and/or research significance, providing trans-generational knowledge
6 Outstanding educational and/or research significance; trans-generation knowledge; great concern about protecting site for educational purposes
9 Unable to assess educational or research significance

Youth education
Elder knowledge
Trans-generational
Culturally-specific
Academic research
Academic education
Non-academic education
Other knowledge

Ethnoecology

0 No record or presence of plant and/or animal species used for food, utilitarian, food, medicinal, ceremonial, or other purposes

1Former presence of ethnobiological resources, but no longer present, or very few ethnobiological resources
2 Only 1 ethnobiologically important species present, or only a few species that can readily be obtained elsewhere
3 Several ethnobiologically important species present, although they can be found elsewhere
4 Several ethnobiologically important species present, of which at least one is difficult to acquire elsewhere
5 Numerous ethnobiologically important species present, with one or more being unique to the site
6 Many ethnobiologically important species present, including many that cannot be found elsewhere
9 Unable to assess ethnobiologically important species

Plants

Used for food
Firewood, constr, etc.
Medicinal purposes
Ceremonial purposes
Extirpated species
Endangered species
Restoration potential
Multiple use/other

Animals

Used for food
Utility animals
Medicinal purposes
Ceremonial purposes
Extirpated species
Endangered species
Restoration potential
Multiple use/other

Ethnoecological processes

Ethnogeological processes

Dyes
Paints
Ceramics

Tribal/Band Historical Significance

0 History of the site has been lost and is not taught in neither academic nor non-academic settings

Site______________________________ Date______________

1 History of the site is very limited and poorly available
2 History of the site is limited, primarily available in unpublished reports (i.e., water resources, cultural preservation office, etc.)
3 History of the site is moderately available and not well known
4 Site history information availability is good and relatively widely known
5 Site history information availability is very good and quite widely known in both academic and non-academic settings
6 Site history information is excellent, and is taught by the elders to other tribal members in both academic and non-academic settings
9 Unable to assess tribal history of the site

Spring on Historic Route

Site Sacredness

0 No record of historical or contemporary site sacredness; no possibility of the site being sacred
1 Site sacredness is very minor; sacredness possible but not specifically recognized
2 Site sacredness is recognized, but has no specific sacred role or function
3 Site sacredness is moderate, related to one specific role or function
4 Site sacredness is fairly high, related to two specific roles or functions
5 Site is highly sacred, related to several specific roles or functions
6 Site is very highly sacred, related to many specific roles or functions
9 Unable to assess sacredness of site

Sacredness of water
Sacredness of traditional foods
Sacredness of materials
Sacredness of medicines
Sacredness of ceremonial substances
Sacredness of archaeological remains
Sacredness of stories
Spirits or divine beings
Passage point to/from other worlds
Significance in afterlife
Site is sacred
Site is sacred for its pristine character
Site important as route or waypoint

National Registry of Historic Places

NRHP Condition

0 Site has no potential for listing with the Tribe(s) or non-tribal agencies
1 Site has not been recognized by Tribe(s) as having potential for NRHP status, or has been recognized as having very little potential
2 Site has been recognized by the Tribe(s) and/or non-Tribal agencies as having low potential for NRHP status
3 Site has been recognized by the Tribe(s) and/or non-Tribal agencies as having moderate potential for NRHP status, but not formally proposed
4 Site is recognized and listed with the Tribe(s), and NRHP status has been proposed
5 Site is recognized and listed with the Tribe(s), and NRHP status is anticipated and pending
6 NRHP status has been fully completed with both the Tribe(s) and the federal government
9 Unable to assess NRHP potential

Application Status

0 No culturally significant properties exist
1 NRHP status application completed
2 NRHP application submitted
3 NRHP status pending acceptance of application
4 NRHP status approved, but process not complete
5 NRHP status approved
6 NRHP status established
9 Unable to assess NRHP process

Recognized by Tribe as worthy of listing
Recognized by agencies as worthy of listing
Application submitted and refused

Economic Value

0 No economic use or sale of springs resources
1 Very little economic value OR formerly of very limited economic value, but no longer used for agriculture, recreation, or ethnobiological economics
2 Low economic value; use or sale of springs resources depends on erratic availability of resources, weather conditions, etc
3 Moderate economic use(s) or value of springs resources, primarily for single family subsistence; limited financial benefits to larger community
4 Good economic uses and sale of springs agricultural, recreation, and/or ethnobiological resources to the Tribe and/or external communities
5 Very good economic uses and sale of springs' agricultural, recreation, and/or ethnobiological resources to the Tribe and/or external communities
6 Tribe receives excellent financial benefits from the use(s) and sale of springs agricultural, recreation, non-use, and/or ethnobiological resources
9 Unable to assess economic value to the Tribe and/or external communities

Single family use/sales
Communal use/sales
Tribal use/sales
Livestock support
Potable water
Irrigation water

Site______________________________ Date______________

Mineral extraction
Mining permits
Electrical power
Recreational visitation
Non-agricultural plants
Non-agricultural animals
Aquatic agric. plants
Wetland agric. plants
Nonhunted ethnofaunal
Native fish
Farmed fish
Fishing permits
Wildlife
Hunting licenses
Real estate
Non-use values
Other economic values

Tribal Legal Significance

0 No legal interest or consideration of the site's resources
1 Little to no legal status; very little outside interest
2 Very low legal status; little outside interest
3 Moderate legal significance – some outside interest
4 Legal status is fairly well established, and the site is fairly well protected
5 Site legal status is clearly established, and may apply to more than one Tribe
6 Site legal status very clearly established; legal standing is an important precedent
9 Unable to assess legal status

Tribal—individual
Tribal-clan
Tribal
Tribal—multicultural
State
Federal
Agency
Other

Tribal Contemporary Use

o Tribal use or non-use value
1 No direct use but may have potential or non-use value
2 One minor use and may have potential non-use value
3 Slight use—2 uses plus some non-use value
4 Moderate use—3-5 uses plus some non-use value
5 Much use—5-7 uses plus some non-use value
6 Extensive use—8 or more uses and non-use value
9 Unable to assess tribal use or non-use value

Tribal water use
External water use
Irrigation use
Agricultural use
Ceremonial use
Fishing use
Hunting use
Gathering use
Educational use
Mineral extraction
Fuel use
Energy use
Aesthetic use
Recreational use
Guiding visitation use
Route in use

Appendix B

Hydrology Variables

Systematic hydrological measurements are needed for classifying, understanding, and monitoring spring ecosystems; however, flow measurement at springs can be difficult or imprecise. Flow and geochemistry add great insight into understanding aquifer mechanics and subterranean flow path duration. Modeling of flow variability requires multi-decadal monitoring, so collecting flow data during each site visit is important. Springs flow may be measured with one or more of the protocols listed below. Such data should be evaluated for quality before being integrated with other physical and bio-cultural information to assess the condition and risks of hydrological alteration to the springs ecosystem (e.g., Wilde 2008).

Meinzer (1923) developed a ranking scheme for springs discharge rate, a scale that is widely used (e.g., Jay and Blair 2005); however, Meinzer's scale is both incomplete and illogical, as it inversely relates rank to discharge and does not capture the range of springs discharges. We prefer the scale presented in Springer et al. (2008), augmented slightly below, which uses a logarithmic SI scale to rank springs discharge rates (Table B.01).

Where and When to Measure

Flow measurement requires planning, both for the logistics of sampling and the equipment to be used. Surveyors should measure flow at the point of maximum expression, which is not likely to be the source but rather some distance downstream. The point of flow measurement should be recorded on the site map and on the hydrology sheet.

Understanding flow variability is important in many situations, and flow can be expected to vary seasonally at most shallow aquifer or low residence-time aquifers. The most conservative flow measurements are made when transpiration losses, seepage into porous substrates, and precipitation contributions are minimal. However, it is equally important to understand the impacts of riparian vegetation, so mid-summer measurements also are relevant. In short, there is no single time of year that is best for flow measurement.

How to Measure Flow

Flow measurement techniques vary in relation to the site (Table B.01), and the Level 2 SSI springs inventory field sheet provides space for documenting the method(s) used to measure springs flow.

Measure the quantity of water discharging from the spring. Replicated flow measurements are needed to develop a trustworthy mean value. We recommend taking at least 3-6 measurements.

If the discharge of the spring is very low, (first magnitude), the discharge measurement may take several minutes and should be initiated early in the site visit. Second to fifth magnitude discharges are relatively faster and easier to measure. Measurement of sixth or higher magnitude discharges (non-wadeable channels) may take as long or longer than first magnitude measurements, but can be done anytime during the visit.

The name, serial number (if available), and accuracy of the instrument used to measure discharge should be recorded as well as any other important observations. Important observations may include signs of any recent high flow events, such as high water marks or oriented vegetation or debris on or above the channel or floodplain.

Table B.01. Discharge magnitudes modified from Springer et al. (2008), ranges of discharge for class, and recommended instruments to measure discharge.

Discharge Magnitude	Discharge (English)	Discharge (Metric)	Instrument(s)
Zero	No discerinable discharge to measure	No discerinable discharge to measure	Depression
First	< 0.16 gpm	< 10 mL/s	Depression, Volumetric
Second	0.16 - 1.58 gpm	10-100 mL/s	Weir, Volumetric
Third	1.58 - 15.8 gpm	.10 - 1.0 L/s	Weir, Flume, Volumetric
Fourth	15.8 - 158 gpm	1.0 - 10 L/s	Weir, Flume
Fifth	158 - 1,580 gpm; 0.35 - 3.53 cfs	10 - 100 L/s	Flume
Sixth	1,580 - 15.800 gpm; 3.53 - 35.5 cfs	.10 - 1.0 m^3/s	Current Meter
Seventh	35.3 - 353 cfs	1.0 - 10 m^3/s	Current Meter
Eighth	353 - 3,531 cfs	10 - 100 m^3/s	Current Meter
Ninth	3,531 - 35,315 cfs	100 - 1,000 m^3/s	Current Meter
Tenth	> 35,315 cfs	> 1,000 m^3/s	Current Meter

Below we list eight methods to measure springs flow.

Portable weir plate

Typically, weirs are used to measure discharge in spring channels which have low to moderate magnitudes of discharge (Figs. B.01 and B.02). It typically has a "V" notch, with either 45°, 60°, or 90° openings through which all discharge in the channel must be focused. The weir should have a scale that indicates discharge. It should have a solid plate below the notch that is driven into the loose material of the stream bed material. Weirs do not work in bedrock or rocky channels. Surveyors should photograph the installation and estimate the percent of flow not captured.

Once placed in the channel, the weir is leveled using a bubble level. The top of the weir plate is made horizontal and the plate is plumbed. Flow through the weir must be stabilized prior to measurement. Surveyors should record the gauge height 3 - 5 times over a 3 - 5 minute interval, then calculate the mean is calculated from the three replicated and recorded. The volumetric discharge (m^3/s or L/s) is calculated using a standard equation specific to the weir plate being used. The accuracy of the weir is dependent on the size of the notch in the weir, the resolution of the scale, and the amount of flow that is not directed through the notch.

Current meter

Current meters are used for measuring flow in wadeable streams, or in wide or high discharge channels where flow cannot be routed into a weir or a flume (Fig. B.03). Measurement locations are selected in a straight reach where the streambed is free of large rocks, weeds, and protruding obstructions that create turbulence, and with a flat streambed profile to eliminate vertical components of velocity.

In performing discharge measurements, surveyors establish a cross section of the channel using a

Fig. B.01: Weir plate.

Fig. B.02: Measuring flow using a weir.

tag line, dividing the cross section into many evenly spaced partial sections, or into sections that capture equal amounts of flow (Wilde 2008). A section is a rectangle with a depth equal to the measured depth at its location and a width equal to the sum of half the distances of the adjacent verticals. At each vertical, the technician records the following observations on a data sheet, (1) the position on the tag line, (2) the depth of the flow measurement, (3) the velocity as indicated by the current meter. The velocity should be measured at 60% of the depth from the surface of water in the channel.

The discharge of each partial section is calculated as the product of mean velocity times the depth at each vertical, summed across the channel to provide total discharge.

Measurements are made by wading the stream with the current meter along the tag line. The person wading the channel should stand downstream of the velocity meter. Because of the safety risks involved in wading a channel, the person wading should not wade in too deep of water or should not use hip waders in swift water without the use of a safety rope or other appropriate safety gear.

New technology in the form of computer-integrated cross-sectional flow measurement is now available (e.g., Flowtracker, Sontek/YSI 2006), greatly improving the accuracy of streamflow measurement in open, wadeable channels. In larger, non-wadeable streams, a cableway and cablecar or boat are used to measure flow across a tagline.

The Parshall Cutthroat Flume

Typically, flumes are used in third to sixth magnitude discharge springs (Figs. B.04 and B.05). Flumes work best in low gradient channels with fine-grained bed material. The wing walls of the

Fig. B.03: The current meter flow measurement procedure.

Fig. B.04: A cutthroat flume is installed in a channel.

Fig. B.05: Example of a flume used to measure flow.

flume are pointed upstream in the channel to focus as much flow as possible through the regular profile of the flume opening. The flume requires free fall of water out the downstream end of the flume. A bubble level ensures that the flume is level on both axes. Flow should stabilize prior to measurement. Surveyors should photograph the installation and record gage height 3 - 5 times over a 3-minute interval. A standard rating curve for the flume is used to translate gage height to discharge. The mean value for discharge (m^3/s or L/s) is calculated and recorded. Surveyors should estimate the percent of flow captured by the flume. The Springs Online database will adjust estimated flow based on these values.

Timed volume flow capture

Timed volumetric measurements are typically used in low magnitude discharge springs having a pour off or other feature that allows flow to be easily captured into a calibrated container. Typically the surveyors construct a temporary earthen dam to divert water through a pipe or constructed channel (Figs. B.06, B.07, B.08, and B.09). Flow is allowed to stabilize prior to measurement. Surveyors use a calibrated container to catch the discharge from the pipe, recording the volume and the time required to fill the container. Flow should be recorded 3 to 6 times, and averaged. Surveyors should also estimate the percent flow captured. It is important to bring several containers and tubes of different sizes.

Float velocity measurement

Two cross sections are measured and marked with flagging along a reach of straight channel. The width and depth of each channel cross section is measured and recorded. Cross section locations are separated to allow for a travel time of >20 sec float time if possible. A float (i.e., wooden disk) is placed in the stream channel and allowed to reach stream velocity before crossing the upstream cross section. The position of the float relative to the channel sides is noted. The float is timed between the two cross sections. This procedure is repeated 3 to 5 times, as the float is placed at different locations across the channel at the upstream cross-section. The velocity of the float is equal to the

Fig. B.06: Timed volumetric flow capture measurement. SIA photo

Fig. B.07: Sometimes alternate methods are necessary to measure flow using the timed volumentric flow capture method. At this hanging garden, surveyors captured dripping water using a tarp.

Fig. B.08: Timed volumetric flow capture measurement. SIA photo

Fig. B.09: Timed volumetric flow capture measurement. SIA photo distance between the cross sections divided by the travel time. The mean value of surface horizontal velocity (m/s) is calculated. To convert mean surface velocity to mean vertical velocity a coefficient of 0.85 is multiplied by the mean surface velocity. Discharge (m^3/s) is calculated by multiplying the value of mean velocity by the average area of the section of the stream channel measured. This method is inferior to the velocity measurement techniques listed above.

Depression/sump

This method is typically used for small pool-forming (limnocrene) springs with no outflow. Surveyors measure the depth of the pool, then quickly bail water from the depression. Either they measure the volume of water bailed out, or calculate the volume of the drained portion of the pool. They then time the refilling of the pool, repeating this procedure 3 to 5 times. The mean value is recorded as the measurement.

Wetted area measurement

In situations where wetted area can be observed but flow cannot be measured (e.g., seepage from walls, helocrene springs with no outflow) surveyors should measure and describe the area of the wetted surface. This can be used as a monitoring metric; some hydrologists use repeat photography as well to document changes in the wetted area of hanging gardens.

Static head change

This method may be used for a relative comparison value for change in the stage elevation of a water body. A metric staff gage is placed in the water body and relative gage elevation is recorded, or efforts are made to locate and record an existing fixed point in or near standing pool and record vertical distance to pool surface. At a later date, the changes in the static head on the staff gage or fixed point are recorded. This measurement technique provides a relative measure of change, but should only be used when no other options exist.

Visual flow estimation

Site conditions, such as dense vegetation cover, steep or flat slope, diffuse discharge into a marshy area, and dangerous access sometimes may not allow for direct measurement of discharge by the techniques listed above. Although visual estimation is imprecise, it may be the only method possible for some springs, and should be regarded as a last resort. Measurements and photographs should be taken to record the surface area wetted or covered by water and observations recorded on the datasheet.

Other Flow Measurement Comments

Subaqueous springs emerge from the floors of streams, lakes, or the ocean floor. Difference methods can be used to estimate flow of larger springs in stream channels. However, measurement in subaqueous lentic settings, such as lake floors or marine settings, may involve measurement of the area and velocity of discharging flow using SCUBA, thermal modeling, or other techniques that cannot be accomplished during a rapid assessment.

Water Quality Measurement

Overview

Field and laboratory water geochemistry methods are described by the U.S. Geological Survey (reviewed in Wilde 2008) and endorsed by the Environmental Protection Agency. In general, air and water temperature, pH, specific conductance, total alkalinity, and dissolved oxygen concentration are measured using daily-calibrated field instrumentation. Water quality samples and measurements are made at the springs source, rather than downstream from the source, to capture to the greatest extent possible characteristics of the groundwater.

Field Measurement

Many devices are available to measure multiple parameters (i.e. multimeters), but each probe needs to be calibrated against laboratory standards each day. In our experience, the more expensive the sampling device, the more likely it is to malfunction in remote field settings. Therefore, contingency planning is recommended, with several backup devices or strategies for obtaining water quality information.

Field water quality measurements of specific conductance (mS/cm), pH, temperature (°C), and dissolved oxygen concentration (mg/L) should follow established U.S. Geological Survey and EPA protocols. In addition to these variables, other probes can be used to measure oxygen reduction potential, salinity, depth, barometric pressure, nitrate, ammonium, chloride and turbidity in the field.

Surveyors should calibrate the instrument at least daily, following the manufacturer's instructions, maintaining a log book with calibration information. The pages from the calibration log book may be scanned and included in the database.

Surveyors should measure field water quality measurements from flowing water as close to the source as possible. In lentic settings, the depth of the pool should be measured at depths of ¼, ½, and ¾ of the total depth. After selecting the measurement location, allow water to contact the instrument sensor for one minute or until values stabilize before recording.

Laboratory Samples

Filtered 100 mL water quality samples can be collected in triple acid-rinsed bottles for laboratory analyses of major cations, anions and nutrients, if desired. One or two filtered water samples also can be collected in 10 mL acid-washed bottles for stable isotope analyses. Prior to fieldwork, wash sample bottles in 10% HCl acid three times and rinse with deionized water. After washing, allow them dry and then cap them.

Latex gloves and safety glasses should be worn for all water sample collection activities. Water samples should be collected at the location with the highest flow. If there is low to very low flow in a pool site, try to collect a sample where the dissolved oxygen content was the lowest when measured during field parameter measurement. If the site has sufficient flow, fill and rinse each container with water from the spring a couple of times before collecting the sample. The sampler should not contaminate the inside of the sampling container or the lid. Fill the 60 and 4 mL bottles with filtered springs water. Label each bottle with a distinctive color of labeling tape to distinguish treatments. Record the site, date, and treatment on the label.

Samples should be stored on ice in the field but not frozen, and transferred to a refrigerator and stored at 4°C, and sent to a certified analytical laboratory for processing. Water samples used to test for nitrogen and phosphate concentrations should be returned to the laboratory for analysis within 48 hr of sample collection, while cation and anion analyses should be completed within 28 days. Analyses should be conducted with appropriate technology (Table B.02).

Fig. B.10: It is important to measure water chemistry as close to the source as possible. It is best to avoid areas where water is greatly disturbed, such as near a waterfall (shown below). Such areas can cause imprecise measurements for Dossolved Oxygen, etc.

Table B.02: Chemical parameters, instrument type, detection limit, sample preparation and recommended sample handling times.

Chemical Parameter	Instrument	Detection Limit	Sample Prep
18-Oxygen (^{18}O)			No filtering or preservation required
2-Hydrogen (^{2}H)			No filtering or preservation required
Nitrogen – Ammonia (NH_3)	Tehnicon Auto Analyzer, or comparable	0.01-2mg/l NH_3-N	Filtered, 4°C H^2SO_4 to pH<2
Phosphorus (PO_4^{-3})	Tehnicon Auto Analyzer, or comparable	0.001-1.0 mgP/l	Filtered, 4°C H_2SO_4 to pH<2
Nitrate-Nitrite (NO_3^-)	Tehnicon Auto Analyzer, or comparable	0.05-10.0mg/L NO_3-NO_2-N	Filtered, 4°C H_2SO_4 to pH<2
Chloride (Cl^-)	Ion Chromatograph	0.5mg/L and higher	Filtered, no preservation required
Sulfate (SO_4^{-2})	Ion Chromatograph	0.5mg/L and higher	Filtered, no preservation required
Calcium (Ca^{+2})	Flame Atomic Absorption Spec.	0.2-7 mg/L	Filtered, HNO^3 to pH<2
Magnesium (Mg^{+2})	Flame Atomic Absorption Spec.	0.02-0.5 mg/L	Filtered, HNO^3 to pH<2
Sodium (Na^+)	Flame Atomic Absorption Spec.	0.03-1mg/L	Filtered, HNO^3 to pH<2

Appendix C

Worksheet and Equipment List

This section contains worksheets and checklists to assist in the Inventory, Assessment, Planning, and Monitoring process.

Restoration Planning

Defining Rehabilitation Goals

This stage is essential before beginning a project. Goals can vary from restoration of one spring or a small suite of ecosystem elements or processes, to full rehabilitation of the site. Meet with all concerned stakeholders to discuss the issues, rationale for action, expected outcomes and benefits, costs, and consequences if the effort is not successful, as well as future commitment to the project, including monitoring.

Defining these parameters in advance can identify potential pitfalls and consequences of actions, which will help focus the planned activities. Before beginning any other planning, it is important to understand the type of springs ecosystem under consideration for rehabilitation, because creating habitats that are inappropriate for a given springs type will likely mean additional maintenance, costs which may not be sustainable over time.

How, by whom, at what cost, and at what schedule are elements of the rehabilitation proposal and the project workplan. Consulting with experts significantly improves chances of project success.

Agencies planning to pursue springs rehabilitation are required to undergo significant review to ensure the importance, cost-effectiveness, and logic of the plan. They should also be involved in framing the monitoring plan. Monitoring is necessary for rehabilitation activities. It provides feedback that helps improve stewardship planning over time (Fig. 4.1). While exhaustive premeditation may not always be necessary, forethought and planning can help lead to project success.

The Planning Process

Like all processes that require forethought and financial investment, springs ecosystem rehabilitation is most likely to succeed when based on a logical progression of actions (Fig. 4.1).

The elements of springs rehabilitation planning and implementation include: assembling the stewardship group (managers, agencies, Tribes, concerned organizations and individuals); introducing the problem and challenges; compilation and understanding of background, inventory, and assessment information; brainstorming and discussion about options; development of a plan, including outreach and information management; securing funding for both management actions and monitoring; conducting or overseeing implementation; and then monitoring and feeding back that information to improve stewardship.

An open, inclusive process helps all concerned with the project understand the process and bring out new ideas and insights that may facilitate the process. The following worksheet provides an easy to follow framework within which to begin the planning process. These are questions that should be considered and answered before, during, and after the restoration process.

Restoration Planning Worksheet SSI © 2015

1. What is the problem?

2. Can the problem be fixed?
   - What is the administrative context?

3. Who cares and why?
   - What is the membership of the stewardship planning and implementation team?
   - Which other individuals and groups are or should collaborate?

4. How will the rehabilitation project be funded in both the short term and long-term?

5. What is the urgency of this project?

6. What are the desired future conditions?
   - Distinguish among flowing (lotic) versus non- or slow-flowing (lentic) springs types

7. What are the rehabilitation goals (broad future vision for the ecosystem)?
   - This will vary in relation the type of springs ecosystem
   - Further refine understanding of desired microhabitats

8. What are the rehabilitation objectives and options?
   - What are the specific management goals (e.g., single species or habitat enhancement, versus whole-ecosystem rehabilitation)

9. If multiple uses are desired, what balance of uses is best and how can those uses best be accommodated?

10. What is likely to be the cost and what are the sources of funding?

11. What is the timeline?

- Including pre-treatment monitoring
- Implementation at 0, 30, 60, 90 and 100% completion
- Include long-term, post-treatment monitoring

12. What are the regulatory and compliance issues and how are they to be resolved?

13. Who is responsible for implementation and oversight, and on what schedule?

14. How will information management and reporting be achieved?

15. How will monitoring feedback be used to improve stewardship?

16. What contingency planning is needed?

- What if……happens?

17. What outreach and partnerships are needed?

18. What long-term stewardship issues need to be resolved and how will that resolution take place?

- How will the long-term effectiveness of the project be guaranteed

Springs Inventory Equipment List

Suggested field equipment:

Science Equipment

- Day pack or backpack
- Background data including maps and directions to site
- GPS unit – set to WGS84 Horizontal Datum, extra GPS batteries
- Laptop with GIS or similar mapping software (optional)
- Field data sheets, extra sets
- Pencils, indelible markers (Sharpies)
- Clipboards
- Handheld dry erase board and markers (level one surveys)
- Graph paper for sketchmap
- Data pouch with waterproof field notebook
- SEAP scoring criteria
- 5 m measuring tape, two 30-100 m measuring tapes or a range finder
- Solar Pathfinder and templates for latitude
- Sighting compass or Brunton compass
- Clinometer
- Trowel or shovel
- Binoculars
- Flash light and extra batteries
- Hand lens
- Munsell soil color chart (optional)
- Water quality kit (EC or SC, pH, temperature, dissolved oxygen)
- Calibration fluids and associated log book
- Handheld thermometer (backup)
- Plant press and newspaper
- Flow measurement equipment
- Natural history field guides
- Camera (memory cards, spare batteries)
- Spray bottle and disinfectant
- Invertebrate collecting gear (optional: 70-100% EtOH, soft forceps, vials, dip and kick nets, aerial net, killing jar and fluid such as ethyl acetate)

Personal Safety Equipment

- Sun protection (hat, bandana, long sleeve shirt, and sunscreen)
- Appropriate clothing (warm layers, rain gear, and synthetic breathable layers for hot weather, closed-toed shoes)
- Clothing accessories (knee pads, work gloves, sun glasses)
- Cell or satellite telephone
- First aid kit and current training
- Drinking water filter (Aquamira, Ketadyne, MSR, etc.)
- Hard hat (if applicable)

Appendix D
Springs Restoration Plant Species

Photo by Max Licher, courtesy of SEInet, http://swbiodiversity.org/seinet/collections/.

Common maidenhair fern (*Adiantum capillus-veneris*)

Wetland Indicator Status: Facultative Wetland.

Elevation & Range: Below 7,500 feet, found throughout southeastern and southwestern states, but also in SD and in BC Canada, where it is associated with particular hot springs. Also found around the world in warm-temperate or tropical areas.

Description: This fern grows in clumps up to 12 inches, spreading through creeping rhizomes. The fronds are usually a pale green with black, wiry, rachis.

Microhabitat at Spring Site: Found growing in damp rocky places along streams or often in cracks or seeps at the base of cliffs.

Special Characteristics: Used as a medicinal plant by many people around the world.

Photo courtesy of SIA © 2015.

Yerba mansa (*Anemopsis californica*)

Wetland Indicator Status: Obligate Wetland.

Elevation & Range: 2,000 - 5,500 feet throughout southwest.

Description: Perennial forb up to 16 inches in height with mostly basal, gray-green, oblong leaves, and very small, densely arranged, flowers on a cone-like spike with white petal-like bracts surrounding the base. Often grows in large colonies.

Microhabitat at Spring Site: Very wet and saline/alkaline soils, or shallow water.

Special Characteristics: Stems root as they grow along the surface of wet soil both stabilizing soil and allowing this plant to move with changes in soil moisture. A traditional medicine of Native American and Hispanic populations.

Saltbush (*Atriplex spp.*)

Four-wing saltbush (*Atriplex canescens*) | Quail bush (*Atriplex lentiformis*)

Wetland Indicator Status: Atriplex lentiformis - Facultative.

Elevation & Range: Atriplex canescens 2,000 - 8,000 feet throughout west. Atriplex lentiformis below 7,000 feet in AZ, CA, UT, NV.

Description: Shrubs up to 11 feet though usually less, and broader than tall. Gray-green leaves are smooth margined and narrow on Atriplex canescens, typically toothed or rippled and broader and triangular on Atriplex lentiformis. Separate male and female plants.

Microhabitat at Spring Site: Atriplex canescens: sandy and/or saline soils. Atriplex lentiformis grows along riverbanks or in the salty soils of salt flats, dry lakes, and desert scrub habitats.

Special Characteristics: Saltbush has deep roots, provides browse, grows quickly and is easily established with container plants or seed. Spread can be controlled through installation of male container plants.

Photo by Max Licher, courtesy of SEInet, http://swbiodiversity.org/seinet/collections/.

Seep willow (*Baccharis salicifolia*)

Wetland Indicator Status: Facultative Wetland.

Elevation & Range: 2,000 - 5,500 feet throughout southwest.

Description: Shrub up to 12 feet tall with willow-like growth and leaves. Leaves are dark green, shiny, waxy and sticky, with small teeth along margins.

Microhabitat at Spring Site: Disturbed sites such as stream sides, and the bottom of dry washes.

Special Characteristics: Dense growth helps to control erosion, also acts as a nurse-plant for riparian tree species. This is an important nectar plant for many species of butterflies.

Photo by Max Licher, courtesy of SEInet, http://swbiodiversity.org/seinet/collections/.

Sedges (*Carex spp.*)

Wetland Indicator Status: Obligate Wetland

Elevation & Range: Most species in AZ grow between 3,500 - 9,500 feet though there are species that grow at both higher and lower elevations. Sedges grow throughout the United States, several species are native to the southwest.

Description: Perennial, grass-like, plants with angular stems (usually triangular), as the saying goes "sedges have edges." Plants spread through rhizomes, some grow in tufts.

Microhabitat at Spring Site: Many species found in wet areas such as along streams, and in marshy areas or seeps. Some species can tolerate drier soils and can be found far from open water sources.

Special Characteristics: Sedges can be easily salvaged and transplanted and provide excellent erosion control.

Photo courtesy of SIA © 2015.

Photo courtesy of SIA © 2015.

Common buttonbush (*Cephalanthus occidentalis*)

Wetland Indicator Status: Obligate Wetland.

Elevation & Range: 1,000 - 5,000 feet in AZ. Found throughout the east, west of Texas it is found only in AZ and CA.

Description: Shrub or small tree up to 10 feet tall. Dark green and shiny leaves grow at each node, opposite or in a whorl. White tubular flowers with long stamens, grow clustered in a ball.

Microhabitat at Spring Site: Wet soil on streambanks.

Special Characteristics: The seeds of this plant are eaten by waterfowl and other birds. The leaves, though somewhat poisonous, are browsed by deer, and the flowers are an important nectar source for hummingbirds and insects, especially bees and butterflies. This plant helps to control erosion when growing or planted on slopes.

Photo by Max Licher, courtesy of SEInet, http://swbiodiversity.org/seinet/collections/.

Saltgrass (*Distichlis spicata*)

Wetland Indicator Status: Facultative or Facultative Wetland.

Elevation & Range: Low elevations in coastal areas, as well as inland sites.

Description: A rhizomatous perennial grass growing erect to a height of about 2 feet or less.

Microhabitat at Spring Site: Commonly found in disturbed sites and in salt flats, this plant can also be found from desert to mountain habitats.

Special Characteristics: This grass is able to survive in soils with high concentrations of salt, which it exudes from its leaves. Some Native Americans would harvest the salt from the leaves. The dense root system forms sod, giving structure and organic matter to the soil. Able to grow in hard soils, mud and even under water. Easily transplantable.

Photo by Max Licher, courtesy of SEInet, http://swbiodiversity.org/seinet/collections/.

Spikerushes (*Eleocharis spp.*)

Wetland Indicator Status: Obligate Wetland.

Elevation & Range: Sea level to 11,000 feet and throughout the US.

Description: Perennial and rhizomatous often forming mats or tufts and growing up to 40 inches, but many species grow less than 1 feet tall. Plants in this genus have no green leaves, but photosynthesize through their stems.

Microhabitat at Spring Site: Most species require moist soils and can be found growing in marshes and wet meadows, and along waterways, seeps, and springs.

Special Characteristics: Some species produce an edible sap, and some have been used to stuff pillows or used to make mats for sitting upon. Like Carex spp., these plants establish easily and provide excellent erosion control.

Scarlet monkeyflower (*Mimulus cardinalis*)

Wetland Indicator Status: Facultative Wetland.

Elevation & Range: 1,800 - 8,000 feet throughout Pacific coast states and southwest.

Description: Perennial forb up to 3 feet with red, tubular, 2-lipped flowers. Lower lip of flower has 3 notched lobes, while upper lip has 2 that arch upwards. Leaves are dark green, oval, opposite, hairy and toothed.

Microhabitat at Spring Site: Wet soils along stream banks, seeps and springs.

Special Characteristics: The stalks of this plant have been a traditional food. This nectar rich plant is pollinated by hummingbirds which transfer pollen on their foreheads as they travel among flowers to feed.

Common yellow monkeyflower (*Mimulus guttatus*)

Wetland Indicator Status: Obligate Wetland.

Elevation & Range: 500 - 9,500 feet throughout west.

Description: Annual or perennial forb up to 3 feet tall. Can grow tall and spindly or shorter and bushy with opposite, round to oval, dark green and toothed leaves. Large yellow flowers with two 'lips" have 5 lobes; the two of the upper lip point upwards while the three of the lower lip point generally downwards and may have one to several red to brown spots. Throat of flower is hairy.

Microhabitat at Spring Site: Grows in saturated soil near seeps or along stream banks and sometimes within shallow water.

Special Characteristics: Able to tolerate in a wide variety of habitats, including the toxic soils of copper mine tailings. Bee-pollinated. A traditional Native American salad green.

Fremont cottonwood (Populus fremontii)

Wetland Indicator Status: Facultative.

Elevation & Range: 150 - 6,000 feet throughout southwest.

Description: Tree up to 40 feet, though sometimes as tall as 80 feet. Bark is smooth when young, becoming whitish, cracked and fissured when older. Trunk can grow up to 4 feet in diameter, though typically less. Leaves are yellowish green, and fairly triangular with toothed margins.

Microhabitat at Spring Site: Stream side and moist soils.

Special Characteristics: A favorite food plant of beavers. Tree is useful for erosion control and for inclusion in riparian buffer zones. Grows quickly and can become established from cuttings/pole planting. Wood used by Native Americans for crafts and ceremonial purposes, leaf buds used medicinally.

Photo by Max Licher, courtesy of SEInet, http://swbiodiversity.org/seinet/collections/.

Mesquites (*Prosopis spp.*)

Honey mesquite (*Prosopis glandulosa*) | Screwbean mesquite (*Prosopis pubescens*) | Velvet mesquite (*Prosopis velutina*)

Wetland Indicator Status: P. glandulosa: Obligate Upland; Prosopis velutina: Facultative Upland; Prosopis pubescens: Facultative.

Elevation & Range: Below 5,000 feet throughout southwest.

Description: Shrubs or small trees up to 30 feet tall. Bark is smooth on young plants but becomes rough and separates into strips with age. Yellow-green leaves are bipinnately compound with oblong leaflets as long as 1¼ inch in *Prosopis glandulosa*, but less than 1 inch long in the other species.

Microhabitat at Spring Site: Along washes and floodplains though sometimes growing on hillsides and in plains.

Special Characteristics: These leguminous trees play an important role in the ecosystems of the southwest. The seed pods are eaten by many wildlife species, and the flowers support many pollinator species. These trees fix nitrogen in the soil and have very deep root systems, some have been found to grow as deep as 175 feet. The wood of these trees is also an important source of fuel and building materials.

Photo courtesy of SIA © 2015.

Willows (*Salix spp.*)

Wetland Indicator Status: Facultative Wetland.

Elevation & Range: Below 11,000 feet, though most species do not grow quite so high in elevation. Range throughout USA, but many local species are native to southwest.

Description: Shrub or tree, some species up to 45 feet. Most species have narrow, lance-shaped, entire or finely toothed leaves.

Microhabitat at Spring Site: Grows at the margins of seeps, streams, rivers and lakes.

Special Characteristics: A food plant for many wildlife species, these plants are also important for erosion control as thick growth can slow water and often deep roots are good at holding soil. Willows grow quickly and can become established with cuttings/pole plantings.

Photo by Sherel Goodrich, courtesy of SEInet, http://swbiodiversity.org/seinet/collections/.

Alkali sacaton (Sporobolus airoides)

Wetland Indicator Status: Facultative.

Elevation & Range: 150 - 7,000 feet throughout west.

Description: Perennial bunchgrass with stems up to 6 feet tall.

Microhabitat at Spring Site: Dry, sandy or gravelly, and often alkaline soils.

Special Characteristics: Abundant seeds are easily distributed by flowing waters; good germination when embedded in sediments. Able to survive high concentrations of salts in soils.

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Index

A

B

C

D

E

F

T

U

V

W

Y