Springs in the Sky Island Region: Inventory, Assessment, and Management Planning Project

Final Report
WaterSMART Agreement No. R11AP81528
Reporting Dates: September 2011 – September 2013

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December 27, 2013

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Protecting our Mountain Islands and Desert Seas

Preferred Citation:

Misztal, L.W., N. Deyo, C.F. Campbell (Sky Island Alliance, Tucson, AZ). 2013. *Springs in the Sky Island Region: Inventory, Assessment, and Management Planning Project*. Final Report to the Desert Landscape Conservation Cooperative for WaterSMART Agreement No R11AP81528; December 2013. 43 pp.

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Acknowledgments

This project was supported by funding from the Desert Landscape Conservation Cooperative through a Bureau of Reclamation WaterSMART grant. Other supporting funders for the project included the Nina Mason Pulliam Charitable Trust, The Kresge Foundation, and the National Fish and Wildlife Foundation.

We would like to say a heartfelt thank you to Jeri Ledbetter and Larry Stevens of the Springs Stewardship Institute. They provided valuable expert input to assist with project design, worked closely with Sky Island Alliance to bring the Springs Inventory Database online, offered creative support and ideas for the project approach, and were enthusiastically supportive of furthering springs research and stewardship in the Sky Island Region.

We would like to thank our federal, state and local partners that supported this project by providing input at springs meetings and climate change adaptation workshops, attending trainings, contributing data and expertise, supporting springs inventory on lands they manage, and supporting improved springs stewardship in the Sky Island Region: Pima County, Bureau of Land Management (especially the Las Cienegas National Conservation Area and Safford Field Office), U.S. Forest Service (Region 3 and the Coronado National Forest), U.S. Fish and Wildlife Service, Bat Conservation International, U.S. Geological Survey, Sonoran Institute, Pima Association of Governments, National Park Service Sonoran Desert Monitoring Network, Arizona Game and Fish Department, Department of Defense – Ft Huachuca, Northern Arizona University, and University of Arizona Water Resources Research Center.

Pima County Department of Natural Resources Parks and Recreation generously provided use of the education facilities at the Agua Caliente Park for two springs inventory protocol trainings during the project, and the County supported the attendance of 8 staff people at the trainings.

The Arizona Riparian Council supported this project by conducting its fall field meeting in the study area and assisting with inventory of springs.

This project would not have been possible without the dedication and enthusiasm of over 100 Sky Island Alliance volunteers that spent their weekends in the field driving rough roads and hiking steep terrain without trails. These volunteers contributed 2,244 hours to this project.

Executive Summary

Introduction

Sky Island Alliance is a non-governmental organizational that works to protect and restore the rich natural heritage of native species and habitats in the Sky Island Region. We work with volunteers, scientists, land-owners, public officials, and government agencies to establish protected areas, restore healthy landscapes, and promote public appreciation of the region's unique biological diversity.

Springs are keystone ecosystems in the Sky Island Region, exert disproportionate influence on surrounding landscapes and are known to be biodiversity hotspots. Although they are abundant in this arid region, they are poorly documented and little studied. They also suffer from extensive human modification and are among the most threatened ecosystems. Lack of information on their location, management context, and biological, hydrological, and ecological characteristics hinders effective stewardship of these resources.

This Springs Inventory, Assessment and Management Project developed new information regarding the biological and management status of springs in the Sky Island Region of southeastern Arizona located at the heart of the Desert Landscape Conservation Cooperative (DLCC) region. Newly collected and previously existing assessment information from the various cooperating agencies (Pima County, Santa Cruz County, US Forest Service, National Park Service, US Geologic Survey, US Fish and Wildlife Service, Bureau of Land Management, and Arizona Game and Fish Department) is now available online regionally and internationally through the Springs Inventory Database. This database is a central repository for inventory information that transcends jurisdictional boundaries and provides information about water availability, its relationship to groundwater basins and its importance to wildlife, plants and humans. This database will provide a much-needed landscape level context for making decisions about management of these crucial resources; this integrated approach was not previously possible due to data being stored by individual agencies in different formats.

This project has enhanced the management of springs in the DLCC by developing new information on the spatial location, temporal attributes, and the biological, hydrological and geomorphological status of springs and seeps at site-specific and landscape scales. These data were applied to management through adaptation planning.

We employed a combination of expert and citizen science inventories and assessments to collect critical baseline information on known springs in areas of interest and priority in the region. We worked with the Spring Stewardship Institute to modify inventory methodologies for citizen scientist data collection. This type of assessment has long been desired by many land and resource managers in the region but has been unattainable by a single entity due to the resource-intensive nature of visiting many springs across the region. This volunteer-driven inventory program is a model for monitoring climate sensitive resources with limited resources.

Methods

To enhance the management of springs in the Sky Island Region of the DLCC, we developed new information on the hydrology and ecology of springs from 2011-2013. Our study area was the Cienega Creek hydrogeologic area within which we identified 118 springs using existing maps, expert input, and survey data. We inventoried and assessed springs within the hydrologic area to collect baseline biological, hydrological and geological data and conducted assessments to characterize springs ecological integrity in relation to human influences. We used geospatially-stratified random sampling to identify a subset of 50 springs for targeted assessment. This allowed us to draw conclusions about springs ecosystems and integrity at a regional level. We visited a total of 61 springs, 45 of which were part of the random-sample study design and 43 of which we were able to locate. We also inventoried all previously unmapped springs that we discovered through field surveys.

We conducted spring inventories and assessments with teams that consisted of at least one Sky Island Alliance staff person trained in springs inventory protocols (or a suitable professional partner substitute) and one or more volunteers formally trained in assessment protocols.

Springs inventories and assessments were part of a larger Sky Island Region project focused on improving the understanding and management of springs. Other project components included extensive coordination with resource managers, development of an online Springs Inventory Database, formal climate change adaptation planning for springs in the Sky Island Region and site specific management planning for springs. Here we present a description of the full project methodology, project outcomes and analysis of the results of springs inventories and assessments. Appendix B includes full reports on the 61 springs examined during the project.

Results

Springs Habitat Area: The sample of 45 randomly-sampled springs for which sufficient data exist occupied a total of 20,120 m^2 or 1.5 percent of the Cienega Creek hydrogeologic area with an average spring area of 464 m^2 .

Springs Types: There are 12 spring types generally recognized (Springer and Stevens 2008). We detected 6 types of springs among the 61 we surveyed with the following order of abundance:

Rheocrene >> Helocrene; Hillslope > Limnocrene; Mound-form > Hanging Garden

Of the 43 randomly sampled springs successfully inventoried, 23 were developed for a development rate of 53% across the study area. Developments at springs primarily included spring boxes, constructed dams, piping to holding tanks or cattle drinkers, and accompanying devices like floats. One of the springs inventoried was classified by the surveyors as anthropogenic because the level of development at the spring made it impossible to discern what the spring type was originally.

Flow: The average flow for springs at which flow was measurable was .14 L/s (n=22).

Elevation of spring sites ranged from a low of 1219 meters at Bootlegger Spring to a high of 2647 meters at Baldy Spring in the Mt Wrightston Wilderness, with an average elevation of 1584 meters.

The distance from springs inventoried to the next nearest spring site ranged from a low of 95 meters at Cottonwood Spring, to a high of 5,208 meters at Paloma Spring with an average distance to nearest spring of 1,629 meters.

Water Quality: Field specific conductance ranged from a high of 880 ųS/cm at Gate Spring to a low of 50.1 ųS/cm at Sycamore Canyon unnamed spring with an average of 518 ųS/cm (n=30). PH ranged from a low of 4.1 at Happy Jack Spring, a spring noted for its visible contamination from nearby historic mining, to a high of 8.45 at Kennedy Spring with an average of 7.1 (n=31).

Springs Flora and Fauna: We collected 907 plant records at surveyed springs, including 227 species identified to the species level, and 102 species identified to the genus level. Of these, 19 species were identified as invasive. There were 8 plant records listed as unknown.

We recorded 123 species of vertebrates and 18 orders of invertebrates. The most commonly recorded families of invertebrates at springs were: Dytiscidae and Hydraenidae, predacious diving beetles and aquatic beetles; Nymphalidae, butterflies; Chironomidae, nematoceran flies; and Belostomatidae, giant water bugs.

Management Considerations

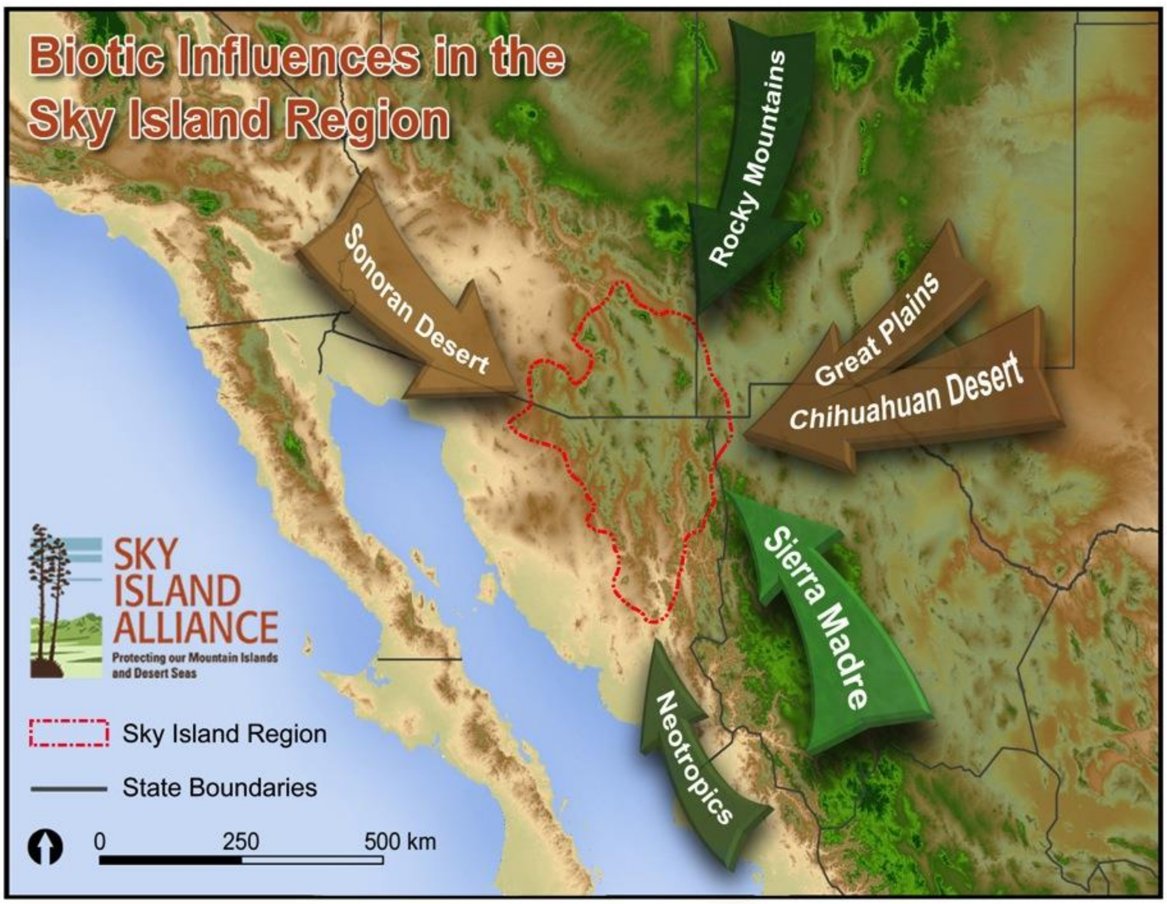
We used the Springs Ecosystem Assessment Protocols to collect information on ecological integrity and threats to natural resource values at individual spring sites. Flow regulation and herbivory exert the most impacts on springs in the Cienega Creek study area followed closely by surface water quality and adjacent land conditions. To identify springs with potential for restoration actions or protective management actions and offer some prioritization of these, we plotted springs based on their natural resource condition and risk scores. Priority spring sites for restoration and protection are described in detail in the results section. Specific management recommendations for individual springs are included in the springs' reports in Appendix B and more general regional recommendations for management are included in the discussion section.

Introduction

Project Need – Adapting to a Changing Climate

This project developed baseline information on springs ecosystems in the Sky Island Region of southeastern Arizona, southwestern New Mexico, and northern Sonora and Chihuahua. The Sky Island Region is located at the heart of the Desert Landscape Conservation Cooperative (DLCC) region. It is characterized by forested mountain ranges "sky islands," surrounded by intervening desert and grassland "seas" and is influenced by the Sierra Madre, Rocky Mountains, and Sonoran and Chihuahuan Desert (Figure 1). Its diverse habitats and topography support many species at the edge of their range, and rare and endemic species, making it an incredibly biologically diverse region.

Figure 1: Map of the Sky Island Region



Arizona is the second most arid state in the continental United States yet likely contains the highest concentration of springs (Springs Stewardship Institute, 2013). Springs in the Sky Island Region have not been systematically inventoried. Information that does exist on springs may be in inaccessible formats, years or even decades old, or only available by jurisdiction. Lack of information on the location, status, ecology, discharge sphere and other information hinders the understanding and effective stewardship of springs ecosystems (Stevens and Mertesky 2008, Misztal 2011).

The first step toward achieving enhanced management of these waters is identifying the current status of springs, including actual location on the ground; current management; human or natural alterations; flora and fauna supported; water production; status of underlying groundwater basin; and contribution of these waters to the watershed where they are located.

Sky Island Alliance (SIA) convened a series of three climate change adaptation workshops focused on natural resource management in the Sky Island Region in 2010, 2012, and 2013.[1] Workshops were designed to identify key natural resource and management vulnerabilities to climate change, and to collaboratively develop implementable strategies to reduce these vulnerabilities. Workshop participants included federal, state and local resources managers, scientists, conservationists, and private land-owners (more information is available at www.skyislandalliance.org/adaptationworkshops.htm and www.Ecoadapt.org/workshops.htm).

Natural resource managers in the Sky Island Region collaboratively developed climate change adaptation strategies to respond to the most pressing threat in the region for natural systems: increasing aridity and scarcity of available water (Misztal 2011; Misztal et al. 2012). Springs emerged as a focal natural resource in this discussion. Strategies developed to reduce the vulnerability of springs and wildlife included:

- Inventory spring locations, conditions and characteristics, species presence and management status.
- Coordinate data sharing across jurisdictions to understand springs in a regional context.
- Prioritize springs for restoration and protective management.
- Coordinate management across jurisdictions to implement protection and restoration of spring ecosystems.

Springs in the Sky Island Region exist in a variety of states ranging from undeveloped and relatively intact to fully altered by installation of structures such as spring boxes or earthen stock tanks. In many instances across public and privates lands, these waters were altered for humans but are no longer being used for the purpose for which they were originally altered, or have been modified far beyond what is necessary for their current use. Many opportunities exist for fully or partially restoring springs to a more natural state that will enhance their value as habitat, water for wildlife, and climate refugia. Additionally, due to the combination of decreasing management resources and increasing threats to resource integrity, opportunities exist to prioritize where and how to focus management activities to generate the best outcomes possible for water and wildlife.

[1] These workshops were supported by The Kresge Foundation and the Nina Mason Pulliam Charitable Trust.

Project Background and Goals

SIA is a non-governmental organizational that works to protect and restore the rich natural heritage of native species and habitats in the Sky Island Region. We work with volunteers, scientists, land-owners, public officials, and government agencies to establish protected areas, restore healthy landscapes, and promote public appreciation of the region's unique biological diversity. Because of our long-standing collaborative relationships with land managers and our large corps of skilled volunteers, we were in a unique position to spearhead this project.

SIA initiated this springs inventory, assessment and management planning project to develop baseline information on springs in the Sky Island Region in order to improve their stewardship in the face of climate change. This baseline information will inform interested agencies and citizens on the condition of these resources and on management actions that can be taken to enhance their resilience in the face of climate change.

This project began in September of 2011 and was completed in September of 2013. The specific goals of the project were to:

- Work collaboratively with land and resource managers to identify priority areas in which to conduct springs inventories and assessments.
- Conduct springs inventories and assessments, using trained volunteers, professional staff, and partner personnel.
- Develop a regional database for housing and serving historic data from cooperating agencies along with new data generated through this project.
- Utilize assessments of current springs management in conjunction with land managers and experts to develop climate change adaptation strategies, decision-support tools, and recommendations for management of priority areas.

This project sought to inventory and assess spring resources in the Sky Island Region, develop an online Springs Inventory Database to house historic and newly collected data, and develop methodologies for a citizen science volunteer effort to inventory, assess, and monitor these waters. We worked collaboratively with land and resource managers to identify priority hydrogeologic areas in which to conduct spring assessments and collect data on the location and other attributes of springs. We worked with the Spring Stewardship Institute to develop inventory and assessment methodologies that capture information most important to managers while being accessible to trained volunteers; and collected new data on priority springs in the region.

Springs Ecology

Springs occur where groundwater reaches the earth's surface (Meinzer 1923). Springs are scattered over all landscapes in the arid southwest, and in the arid regions of North America, they often capture our imagination as lush oases within harsh landscapes. There are many lenses through which to view the value of springs: archaeologists have shown how springs were the focus of many Native American activities; hydrologists understand them as windows into ground water systems; ecologists see them as biodiversity hotspots; ranchers often rely on them as water sources for livestock; and conservationists recognize that they are important riparian and aquatic systems critical to the survival of many obligatory spring-dwelling animals and plants. In spite of these recognitions, springs have been largely neglected as important cultural, scientific, and economic resources, and most have been altered by human activities. As a consequence, few springs have retained their natural character and their fauna have experienced some of the highest extinction rates known in North America (Stevens and Meretsky 2008). Stevens and Meretsky characterize springs as among the most threatened ecosystems.

Springs often function as keystone ecosystems – although they occupy a small area on the landscape, they play disproportionately large roles in the ecology of the surrounding landscape (Peral and Stevens 2008). However, despite their utility in land management practices and the growing recognition of their ecological importance, the functional and ecological status of springs remains largely unknown.

It has only been in recent years that a consistent classification system has been developed to describe springs ecosystems (Springer and Stevens 2008). This is a key step forward for the understanding and study of springs ecosystems. This system provides a framework for springs ecosystem conservation, management, and restoration. Springer and Stevens (2008) identify 12 types of springs which they refer to as "spheres of discharge." The following six springs types are relevant to this project. Please see Springer and Stevens (2008), and Appendix A for further information.

- *Rheocrene* springs are flowing springs that emerge in one or more channels.
- *Helocrene* springs emerge from low gradient wetland and often have indistinct or multiple sources seeping.
- *Hillslope* springs emerge on a steep (30-60°) slope and often have indistinct or multiple sources.
- *Limnocrene* springs emerge in pools.
- *Mound-form* springs *e*merge from (usually carbonate) precipitate mounds or peat mounds.
- *Hanging Garden* springs usually emerge horizontally along a geologic contact along a cliff wall and display dripping flow.

Other Regional Efforts Benefiting from this work

In the Sky Island Region, numerous partners were already mapping, monitoring, inventorying or otherwise paying some attention to select springs under their stewardship. We coordinated with the following extant initiatives during our project: a spring snail assessment on Fort Huachuca, identification of springs in the Santa Rita Mountains near a proposed copper mine, a U.S. Geologic Survey (USGS) project to map surface water in Arizona using Google Earth imagery, ongoing *tinaja* and spring monitoring in association with ranid monitoring at Saguaro National Park, monitoring and assessment of cienegas on Las Cienegas National Conservation Area, and preparation for adjudication of water rights on the Coronado National Forest.

At the start of the project, the Coronado National Forest had completed a forest-wide effort to map all springs on their lands and had contracted with a private consultant to conduct surveys of springs in the Santa Rita Mountains as part of the environmental analysis for the proposed Rosemont Mine. Pima County acquired land and resource management responsibilities on 225, 000 acres of land in eastern Pima County over the past 6 years and was collecting information on the location, status, and trends of key natural resources and threats to those resources. In 2010-2011 the County mapped surface water sources that are not dependent on human-built water-delivery tools (Powell 2011). Pima County has a long history of data collection on riparian and aquatic features through regional assessments to inform and implement the Sonoran Desert Conservation Plan (see www.pima.gov/cmo/sdcp/).

Methods

Engaging Partners

This project grew directly out of collaborative climate change adaptation planning efforts at which scientists, resource managers, land owners and conservationists identified the regional adaptation strategy of inventorying, and prioritizing springs ecosystems in order to taking informed management actions. The project was designed to be responsive to the information and management needs of regional land managers. To ensure we were adequately responding to information needs of local managers, we did broad outreach to agencies, conservation organizations, tribes, research institutions and private landowners that had previously expressed interest in springs or that we knew had springs resources under their stewardship. Through emails and phone calls, we informed potential partners of our intent to implement the springs climate change adaptation strategy and convened an initial planning meeting in the spring of 2011. We contacted previous climate change workshop participants and partners we were already working with on Chiricahua leopard frog recovery and riparian habitat protection. At the initial meeting we introduced our project idea and expressed our intent to seek funding for the project. We asked participants to share their management interests in springs, existing regional data, and to identify who they thought was missing from the meeting that should be involved.

Once we received funding for this project we convened a project kick-off meeting in early 2012. Larry Stevens with the Springs Stewardship Institute joined us to present his work on springs ecology and inventories to the group. We then discussed participants' immediate information needs regarding springs ecosystems, and potential ways to focus our survey efforts (e.g. geography). As the project progressed, we held a second coordination meeting with the primary objective of selecting the study site. See the results section for further discussion of partners.

Study Area Selection and Description

We decided to focus our efforts on one hydrogeologic/watershed area in the region in which to inventory and assess springs. To ensure that we were gathering information where it was most needed, we held a partner meeting in the spring of 2012 to determine which area was of highest priority to the group. Project partners at the meeting included the Coronado National Forest, Pima County, Arizona Game and Fish Department (AZGF), Bureau of Land Management (BLM) Safford Field Office, U.S. GS, U.S. Fish and Wildlife Service (USFWS), Desert Botanic Garden, and Pima Association of Governments. Partners were presented with summary information for HUC 8 watersheds and groundwater subbasins within the region. The project partners chose the Cienega Creek area as the highest priority due to the diversity of land tenure and agency management units present, the accessibility of spring sites, the recognized importance of the area to regional conservation, the existence of current conservation projects, the potential for restoration efforts, key data gaps, and the current threat of a large proposed copper mine in the area that managers are concerned will affect water resources.

To better capture the relationship between groundwater and surface water, we developed a study area informed by hydrogeologic areas, as defined by Anning and Konieczki (2005). The Cienega Creek study area is comprised of 843 square miles (1382 square km) and includes 118 documented springs (Figure 2). Hydrogeologic areas consist of coincident ground-water and surface-water basins (Anning and Konieczk 2005). The study area encompasses portions of Pima, Santa Cruz, and Cochise Counties in southern Arizona and abuts the U.S.-Mexico border. The study area contains the following biotic communities (Brown and Lowe 1981) petran montane conifer forest (4,927 acres), Chihuahuan desertscrub (32,053 acres), plains and great basin grassland (114,976 acres), semidesert grassland (176,552 acres), and Madrean evergreen woodland (211,322 acres) (Figure 3).

Significant management units in the area include Las Cienegas National Conservation Area managed by the BLM; the Santa Rita, Rincon, Whetstone and Huachuca Ecosystem Management Areas of the Coronado National Forest managed by the U.S. Forest Service (USFS); and Cienega Creek Preserve and other conservation lands managed by Pima County.

Figure 2: Study Area Map

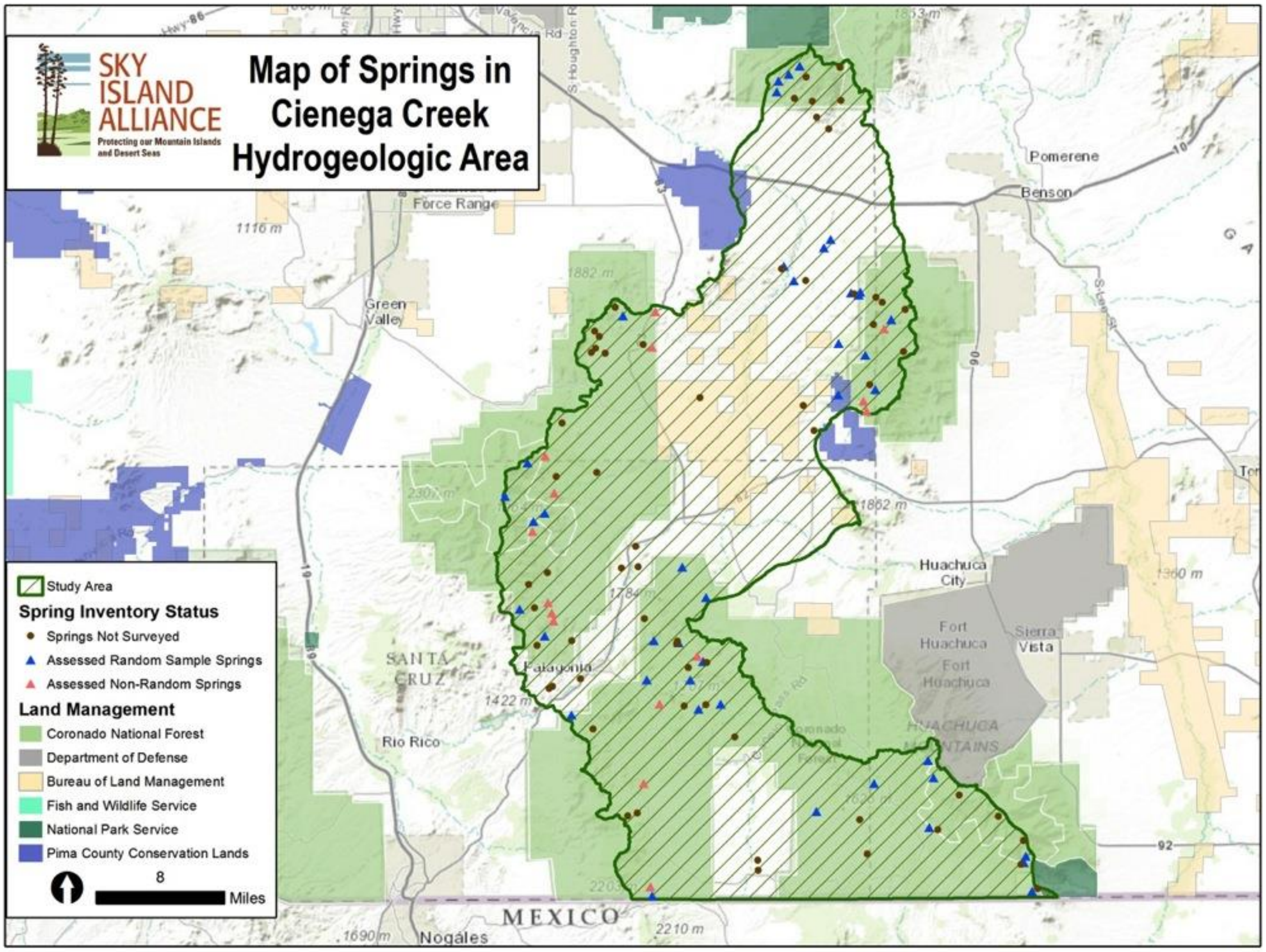
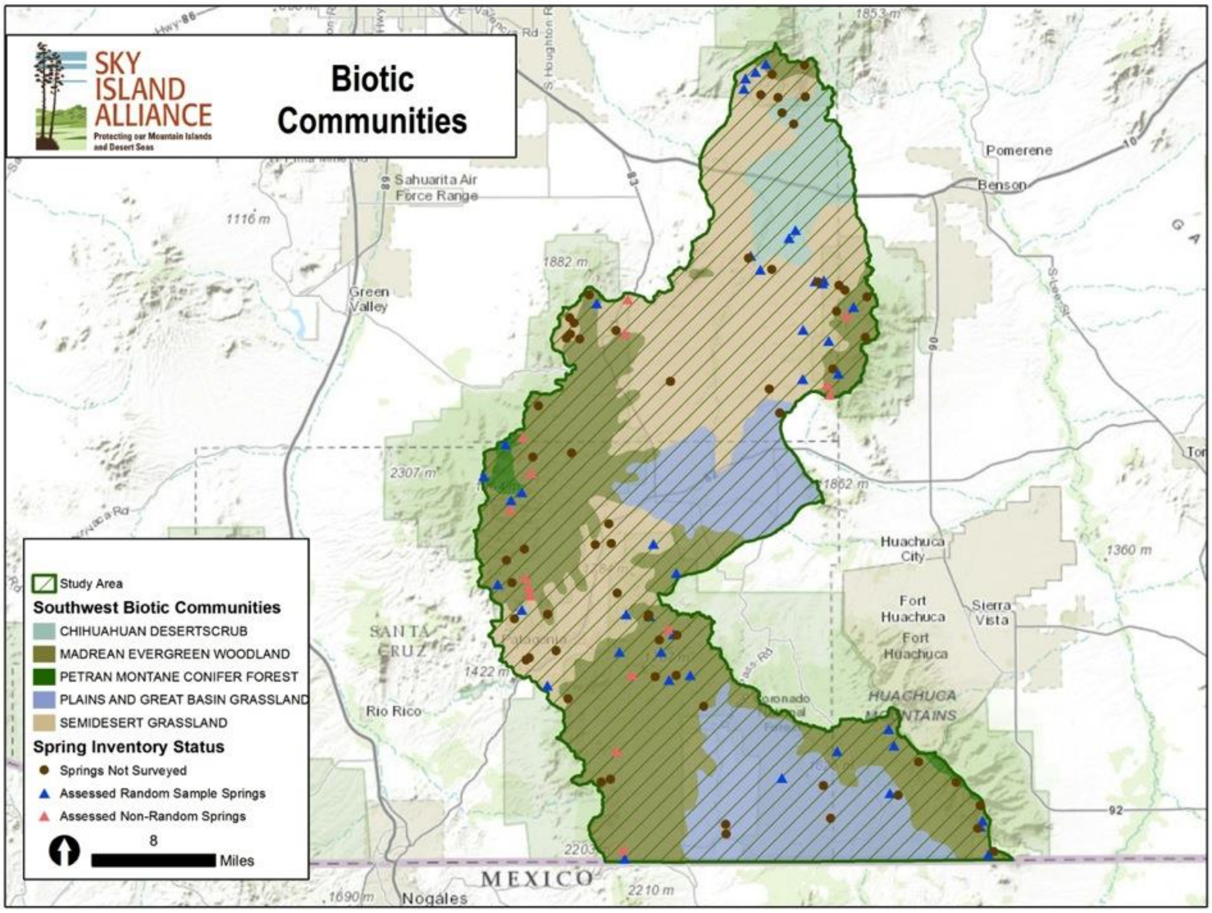


Figure 3: Map of Biotic Communities in the Study Area



Information Sources

Prior to conducting field work, we attempted to locate all springs in the Cienega Creek study area. We started with a spatial data set from the Springs Stewardship Institute that included data from the Arizona Land Resource Information System (1993), Arizona Geologic Information Council (2008) and the National Hydrology Dataset. We collected further spatial datasets from the Coronado National Forest, Pima County, The Nature Conservancy, SWCA Environmental Consultants, and the USGS, all of whom had done some sort of spatial survey work in the area. These data sets were cross-referenced with the Springs Stewardship Institute dataset. Finally, we visually scanned USGS topographic maps to include mapped springs that were not accounted for in the mentioned data sets.

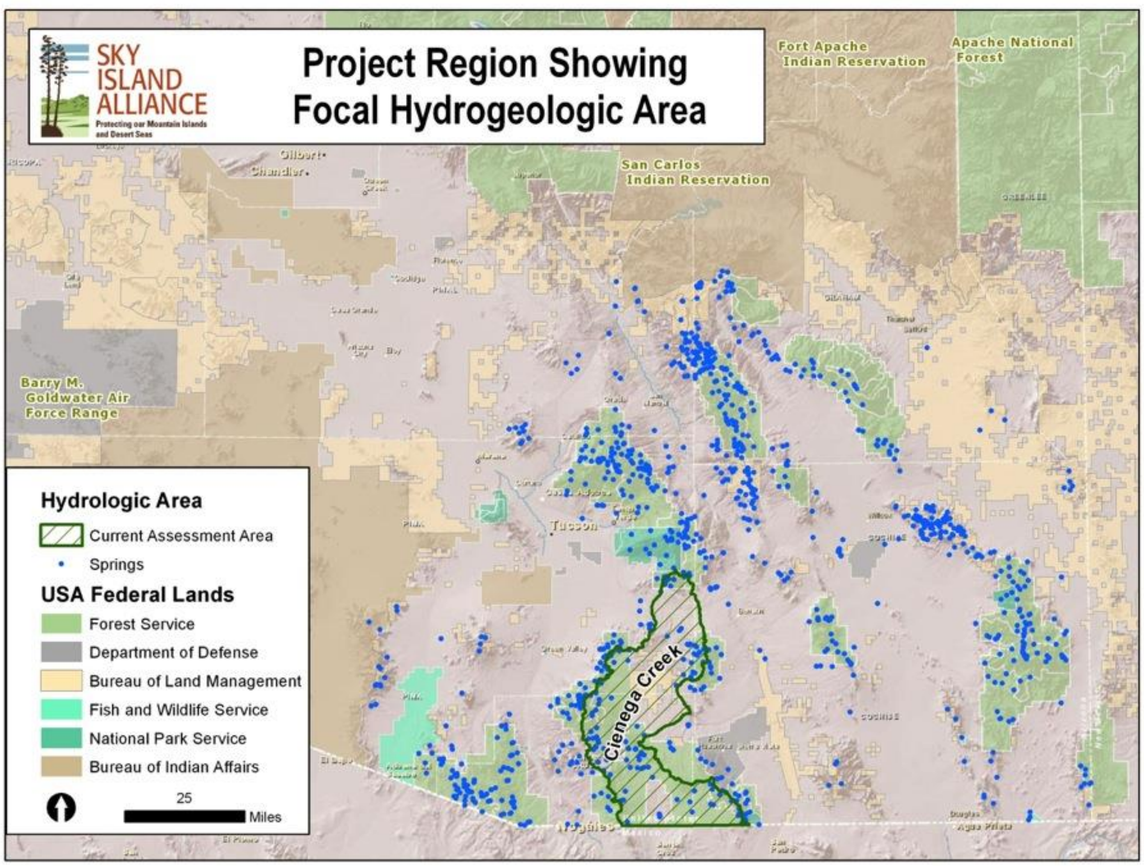
Random Sample Design

In order to develop an understanding of springs health, characteristics, and management needs at a landscape-level, we used a clustered random sample design to determine sites for survey. Survey sites were selected by analyzing all 118 springs in the study area based on their X, Y, and Z coordinates to create "spring clusters," then randomly selecting one or more springs within each cluster to reach a random sample size of 50 springs. We choose a sample size of 50 to get adequate representation of springs across the study area based on expert input from Dr. Larry Stevens of the Springs Stewardship Institute. We used a cluster-based random sample to ensure springs were inventoried across a range of elevations, levels of geographic isolation, and ownership status in order to support a landscape scale ecosystem assessment. This methodology ensured we were not limiting our survey sites to springs that were well-known, easily accessed, or of high management interest to our partners but were gathering a broad sample of springs.

If we were unable to visit a spring in the random sample of 50 due to access or other issues, we moved down the list to the next spring in the sample. In addition to the randomly selected springs, we opportunistically assessed "non-random" springs that were in close proximity to random springs, and select springs that were of high management concern or high priority to partners. Figure 2 shows the randomly selected and other springs that were visited over the course of this project.

This study framework provided two crucial types of information—a landscape-scale assessment of spring ecosystems within the Cienega Creek study area and specific data on the ecological conditions at individual springs.

Figure 4: Map of Arizona Sky Island Region



Field Methods

Because little or no baseline data existed for springs in the Cienega Creek study area at the start of the project, our primary objective was to collect baseline data on springs. We worked with Larry Stevens and Jeri Ledbetter to adapt inventory and monitoring protocols originally developed by the Springs Stewardship Institute (Stevens et al. 2012) to meet the requirements of this project. This was necessary because SIA took the approach of utilizing trained volunteers as the main workforce for accomplish springs surveys (Figure 5). Volunteers that participated in the project had varying levels of naturalist or scientific expertise. To accommodate this, we developed protocols that struck a balance between Type I Inventory, that collects solely geographic information on springs, and a Type II Inventory that collects physical, biological, geomorphological, geological, human impacts and administrative context variables for springs (Ledbetter et al. 2010; Stevens et al. 2012).

Survey teams typically ranging in size from 2-5 people visited springs. To ensure data quality, consistency, and compliance with survey protocols, volunteer teams were always accompanied by an SIA staff member trained in the protocols, or by a reliable substitute from a partner organization. We structured volunteer teams so that a diversity of expertise was represented. For example, a staff-volunteer team might include a birder, a botanist, a geographer, and a biologist. We conducted field work through a combination of day trips to isolated springs and volunteer weekends where we camped at a single location that was in close proximity to a cluster of springs.

Figure 5: Volunteer Conducting Springs Inventory in the Field

We held a formal springs inventory and assessment protocol training in April of 2012 (Figure 6). Training consisted of two days, equally split between classroom time focused on springs ecology, geology and hydrology, and field exercises to practice assessment techniques at nearby springs.

Figure 6: Volunteers Learning to Use a Solar Pathfinder at the Springs Inventory Protocols Training

To maximize both accomplishments within the funding period and volunteer engagement opportunities, we conducted surveys throughout the seasons. Ideally, biological inventory would be conducted during the growing season to capture flowering and breeding, while hydrological and geological surveys would be conducted in winter to capture peak baseflow information (Stevens et al. 2011). These different considerations for timing of surveys highlight the importance of additional site visits in different seasons and of monitoring (see Next Steps p. 40 for further discussion). The data collected through this project provides a snapshot in time of each of the springs visited.

At all springs sites that were located the following inventory data were collected:

Site Overview Information: includes GPS location, elevation, spring sphere of discharge, site condition at time of visit, site description, directions to site, surveyors names and survey time. The spring sphere of discharge is based on the combination of source flow and physical characteristics of the site (Springer et al. 2008) (see Appendix A for more information). This overview information is necessary to map the spring, re-locate the spring during subsequent visits, track changes in spring condition over time, and to relate springs to management areas and activities. Equipment used included a GPS device, a compass, and a clinometer.

Site Map: includes a map with a scale, area measurements, true north, the location of photographs, the location of variables measure including water, GPS and solar radiation measurement points, and spring microhabitats labeled (Figure 7). Maps were drawn to include the area directly influenced by the spring. The sketch map synthesizes locations of geomorphological landmarks and biological characteristics, allows for repeat measurements, and measures the area of springs sites and microhabitats. Equipment used included a 30 meter tape measure and graph paper.

Photo Documentation: includes an overview photo of the site taken near the source point looking down channel, a secondary photo likely taken below spring emergence looking up channel, and any other objects of interest. Photos provide an overview of site geomorphology, hydrology, biology and condition.

Solar Radiation: includes recording a sunrise and sunset time for each month of the year. A Solar Pathfinder was used to record a total solar budget for the site. The amount of solar budget at a site determines light energy available for photosynthesis, duration of freezing in winter, evaporation and relative humidity and is therefore an important factor in microclimate (Stevens et al. 2006; Stevens et al. 2011). A Solar Pathfinder is a relatively inexpensive tool for collection of solar radiation data and provides finer resolution than can be provided through a GIS analysis. This is important when surveying springs that are very small in total area, or are located on vertical surfaces or in steep terrain.

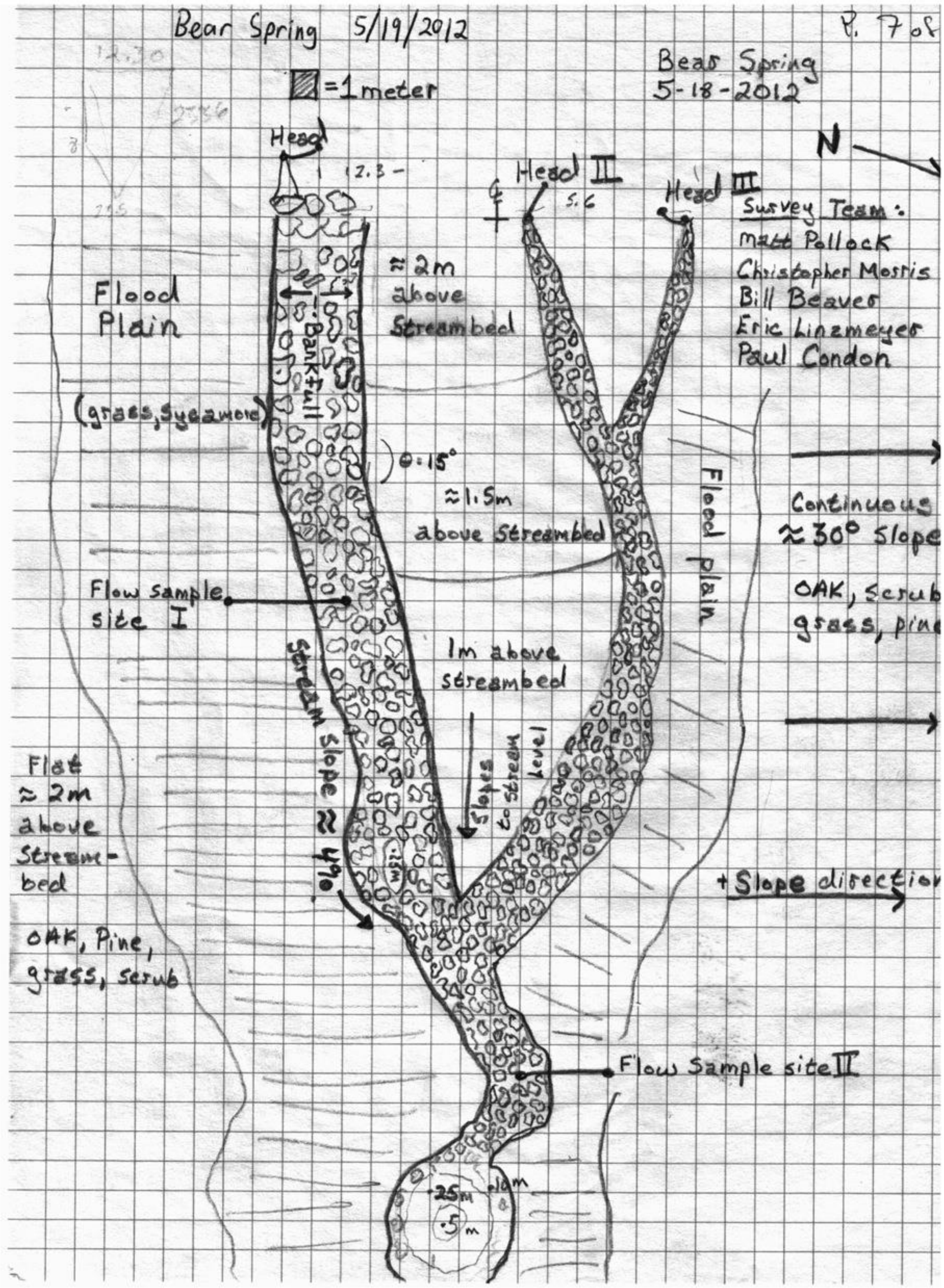
Flora and Fauna: includes lists of plant and animal species present or identifiable by sign or calls with careful attention to the presence of sensitive and invasive organisms. This was done to the best of the ability of the survey team and was intended to get an initial snapshot of the species present at springs.

Flow: Flow rate measurements were taken when possible. Surveyors used a simple timed volume capture protocol. Flow is one of the most important and useful variables for understanding what biotic components a spring can support and the level of its functioning, and is sensitive to anthropogenic influences such as water extraction. Equipment used included PVC piping of various sizes, calibrated capture cups ranging from .75 L to 1.5 L, and a stopwatch.

Water Quality: includes pH, specific conductance, temperature and dissolved oxygen. Water quality was measured as close to the source as possible. Water quality measurements were taken in the field using the YSI Multiparameter instrument that was calibrated at the start of every field work day. Near the end of the project we began using a smaller handheld water quality instrument, the Hannah Handheld Combo meter because it was more accessible to volunteers. This instrument was used to measure pH, specific conductance, and temperature.

In addition to the inventory data listed above, crews performed Springs Ecosystem Assessment Protocols (SEAP). This set of protocols was developed by the Springs Stewardship Institute and collects information regarding the ecological condition, risks, and restoration potential of springs. Characteristics scored by the assessment fall under the following categories: Aquifer/Water Quality, Geomorphology, Habitat, Biotic Integrity, Human Influence, and Administrative Context. Specific characteristics under each of these categories are scored on a scale of 1-6 and are given a score for both condition and risk based on a detailed scoring rubric. See Appendix A for detailed assessment protocols, scoring rubric, and field forms. Assessed springs can then be ranked based on specific stewardship objectives, providing a roadmap for management options at a specific spring. This information can also be examined in aggregate across a study area or region of interest to develop an understanding of overall conditions and threats for the region. Springs inventories and assessments provide an understanding of springs' ecology in context with local and regional threats including ground and surface water extraction, contamination, livestock use, human alteration of the site, recreational impacts, and climate change.

Figure 7: Sample Site Map



Management Planning and Outreach

A key component of this project was continued engagement of managers to gather input, share results and ensure that the project was progressing in a manner consistent with management and conservation needs. Throughout the project we maintained communications and coordination with more than 20 entities that make up the informal regional springs stewardship network. We coordinated through a combination of in-person meetings, regular email contact with the full group to update them on project progress, and more formal regional information sharing via the Las Ciengas National Conservation Area biological meetings and scenario planning, a regional climate change adaptation workshop, and coordination with Chiricahua Leopard Frog recovery efforts.

To reach managers beyond our active regional partner group, we presented on this project at a number of broad reaching venues including conferences focused on natural resource management and adaptation to climate change, workshops, and symposia. We also gave targeted talks to specific audiences such as the Hydrologist for Region 3 of the US Forest Service. Our presentations focused on sharing project methodologies in addition to results.

Results

We conducted inventories at a total of 61 springs in the Cienega Creek study area (Table 2). 45 of the springs were part of the clustered random sample, 5 springs were opportunistically sampled, and we documented 11 springs that had not previously been mapped. Of the 45 springs that were part of the random sample two were unlocatable by surveyors. For purposes of analysis – drawing conclusions about springs across the study area - we only analyzed the randomized sample set. As part of the springs inventories protocols trainings, we assessed two springs that were not in the Cienega Creek study area. Full spring inventory reports are available for all springs surveyed in this project in Appendix B. The project results are described below in two sections - one describing the analysis results from springs inventories and assessments and one describing overall project outcomes.

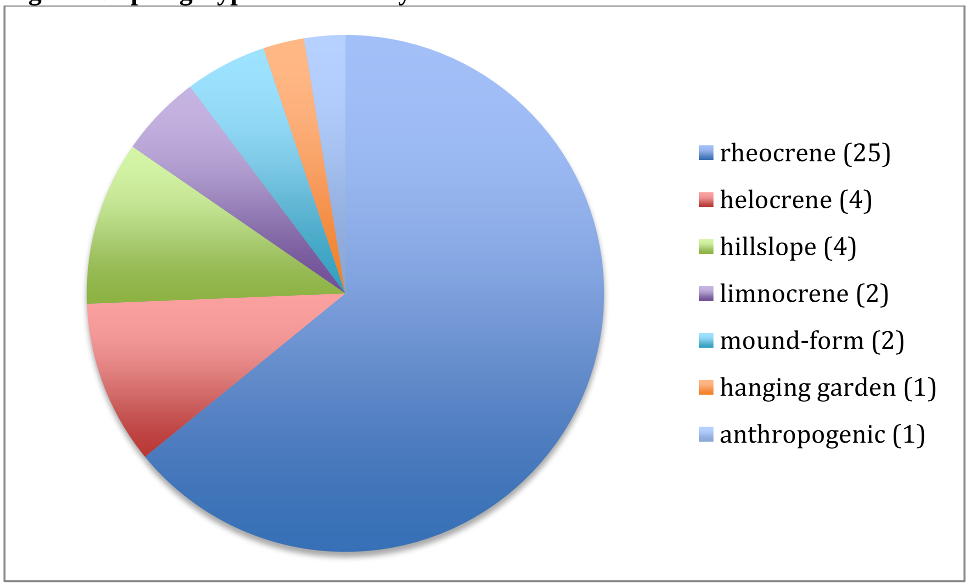
Basic Statistics Across Random-Sample Springs

Springs Types: There are 12 spring types recognized (Springer and Stevens 2008). We detected 6 types of springs among the 61 we surveyed with the following order of abundance (Figure 8):

Rheocrene >> Helocrene; Hillslope > Limnocrene; Mound-form > Hanging Garden

One spring was classified as anthropogenic because it was too developed to determine the original discharge sphere. Of the 43 randomly sampled springs successfully inventoried, 23 were developed for a development rate of 53% across the study area. Developments at springs primarily included spring boxes, constructed dams, piping to holding tanks or cattle drinkers, and accompanying devices like floats.

Figure 8: Spring Types in the Study Area



Springs Habitat Area: Spring site area calculated from site sketch maps ranged from a low of 1 m^2 at Yaqui Spring to a high of 5000 m^2 at Nogales Spring with an average spring area of 464 m^2. The total area encompassed by springs surveyed in the Cienega Creek study area was 20,120 m^2 or 1.5% of the (1,381,967 m^2) study site.

Elevation: Elevation of spring sites ranged from a low of 1219 meters at Bootlegger Spring to a high of 2647 meters at Baldy Spring in the Mt. Wrightson Wilderness, with an average elevation of 1584 meters.

Isolation: The distance from springs inventoried to the next nearest spring site ranged from a low of 95 meters at Cottonwood Spring, to a high of 5,208 meters at Paloma Spring with an average distance to nearest spring of 1,629 meters.

Flow: Of the 45 randomly sampled springs, surveyors were unable to locate two indicating they were likely dry for some extended period of time. Another four of the 45 randomly sampled springs were located and inventoried but had no water present on the site at the time of visit. 39 or 86% of the springs had some water present at the site at the time of survey.

For the springs with sufficient flow present to measure, the flow rate ranged from a high of 0.6 L/s at Sawmill Spring to a low of 0.00004 L/s at Ranger Station Spring. The flow was not measured at 17 springs that had water present due to one of the following: pooled water prevented capturing flow, the flow rate was low enough that water could not be captured for volumetric measurement (e.g. wetted soil present), or the presence of infrastructure prevented measurement. The average flow rate for the study area was 0.14 L/s (n=22). Table 1 shows average flow by spring type. Figure 9 shows the relationship between flow rate and elevation for the study area.

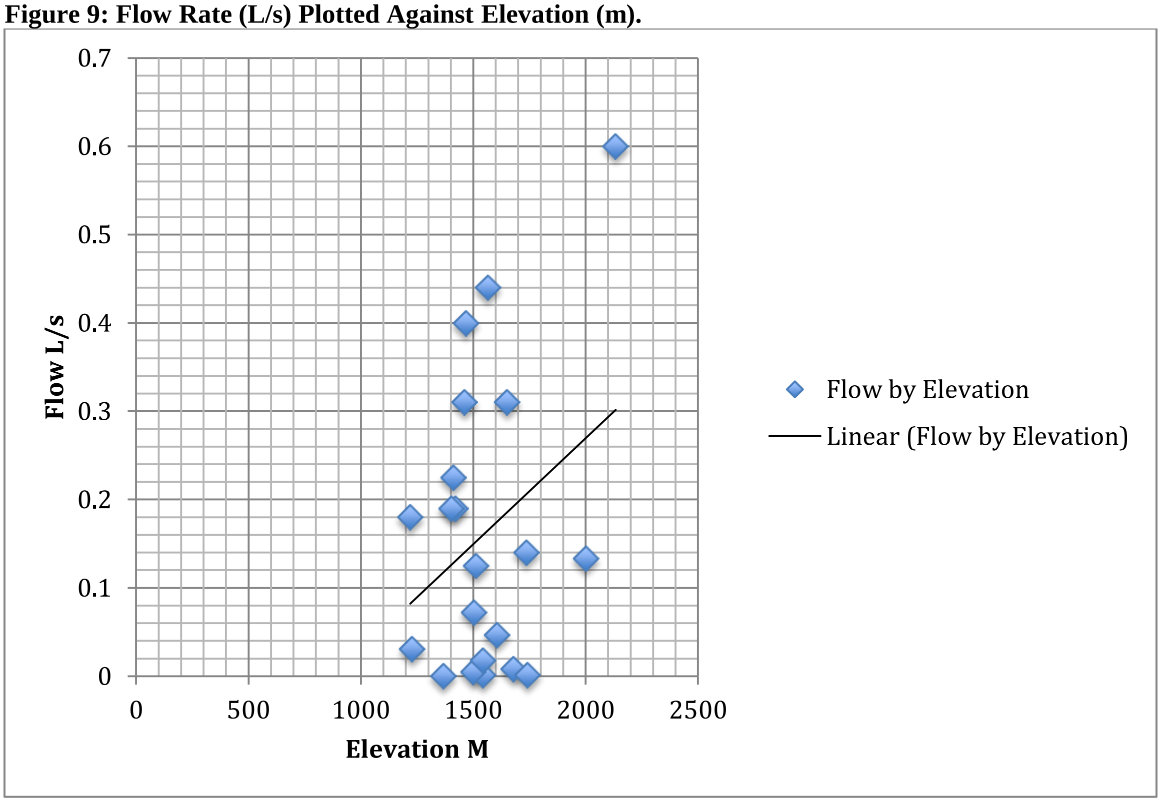
Table 1: Average Flow by Spring Type

Spring type	Average Flow at Measured Springs
Rheocrene	1.9 L/s
Hillslope	0.6 L/s
Limnocrene	0.3 L/s

Water Quality: Field specific conductance ranged from a high of 880 ųS/cm at Gate Spring to a low of 50.1 ųS/cm at Sycamore Canyon unnamed spring with an average of 518 ųS/cm (n=30)

PH ranged from a low of 4.1 at Happy Jack Spring, a spring noted for its visible contamination from nearby historic mining, to a high of 8.45 at Kennedy Spring with an average of 7.1 (n=31).

Figure 9: Flow Rate (L/s) Plotted Against Elevation (m).



Flora and Fauna: The flora and fauna analysis is limited by the constraint of spring survey teams having varying plant and animal identification skill sets. Also springs across the study area were visited at different times of the year. Thus, the plant and animal species lists provide an initial snapshot of diversity present at each spring.

We collected 907 plant records at surveyed springs, including 227 species identified to the species level, and 102 species identified to the genus level. Of these, 19 species were identified as invasive. There were 8 plant records listed as unknown.

We collected invertebrate observations at 27 springs and recorded an array of invertebrates. We recorded 18 orders of invertebrates. The most commonly recorded families of invertebrates at springs were Dytiscidae and Hydraenidae, predacious diving beetles and aquatic beetles; Nymphalidae, butterflies; Chironomidae, nematoceran flies; and Belostomatidae, giant water bugs.

We collected vertebrate observations at 35 springs. We observed 123 species of vertebrates: 14 species of reptiles and amphibians including Chiricahua leopard frog Sonoran mud turtle; 15 mammal species, 4 fish species; and 89 bird species. Invasive vertebrate species recorded at springs include crayfish, bullfrog, mosquito fish and carp. The greatest number of vertebrate species recorded at a single spring was recorded at Wakefield Spring. The most commonly recorded vertebrates were:

Javelina > Domestic Cow > Bewick's Wren, Hepatic Tanager, and Tree Lizard

Solar Radiation: Solar Pathfinder data show that solar radiation budgets in the study area vary greatly. Sites ranged from being fully exposed to direct solar radiation (receiving 100% direct solar radiation) to a low of 72% direct solar radiation at Wakefield Spring, an exposure spring emerging from a cave.

Table 2: Springs at which Inventories were conducted in the Cienega Creek Study Area Including Date, Area, Spring Type, Elevation, Coordinates and County.

Site Name	Date	Area (m²)	Spring Type	Elevation M	UTM E	UTM N	County
Alamo Spring	7/21/12	510	rheocrene	1512	532478	3499844	Santa Cruz
Aliso Spring	5/19/12	no map	rheocrene	1780	518707	3511126	Pima
Apache Spring	3/16/13	447	helocrene	1466	548162	3522428	Pima
Baldy Spring	5/19/12	35	helocrene	2647	514615	3507093	Santa Cruz
Barrel Spring	5/20/12	144	anthropogenic	1303	530101	3525765	Pima
Bart Spring	3/29/13	no map		1895	544261	3550350	Pima
Bear Spring	5/19/12	604	rheocrene	1736	518360	3505350	Santa Cruz
Bear Spring	3/15/13	20	hillslope	1746	551000	3515630	Pima
Benton Spring	1/12/13	650	rheocrene	1646	529248	3467796	Santa Cruz
Blacktail Spring	3/17/13	59.5	hillslope	1499	549917	3517161	Pima
Bootlegger Spring	10/4/13	no map	rheocrene	1219	542669	3530204	Pima
Burro Spring	12/8/12	306	rheocrene	1736	553380	3524769	Cochise
Chimney Spring	3/29/13	190	rheocrene	1565	543202	3549552	Pima
Collins Spring	6/17/12	1989	limnocrene	1650	551779	3478196	Cochise
Copper Mountain unnamed	1/12/13	no map	rheocrene	1440	533908	3491052	Santa Cruz
Cott Tank	10/28/12	450	rheocrene	1543	536336	3486185	Santa Cruz
Cottonwood Spring	1/12/13	0	rheocrene	1461	534860	3490306	Santa Cruz
Cottonwood Spring	3/16/13	63	rheocrene	1573	551854	3512101	Pima
Coyote Spring	12/8/12	no map	exposure	1620	552760	3523962	Cochise
Death Trap Spring	3/16/13	105		1678	551966	3517866	Cochise
Dripping Spring	3/14/13	383	rheocrene	1402	518976	3496376	Santa Cruz
Farrell Spring	4/26/13	271	mound-form	1583	528724	3478231	Santa Cruz
Flux Canyon	4/26/13	101.5	anthropogenic	1242	521340	3485090	Santa Cruz
Gate Spring	1/12/13	280	rheocrene	1411	533260	3488531	Santa Cruz
Goat Well Spring	3/16/13	760	rheocrene	1586	550427	3512994	Pima
Happy Jack Unnamed	2/2/13	1800	rheocrene	1604	516124	3495761	Santa Cruz
Harshaw Creek unnamed	10/27/12	275	rheocrene	1341	530205	3486090	Santa Cruz
Hidden Spring	11/21/12	375	rheocrene	1210	542035	3547853	Pima
Johnson Spring	2/2/13	300	anthropogenic	1371	518629	3493030	Santa Cruz
Juniper Spring	3/18/13	414	rheocrene	1561	554974	3513159	Cochise
Kennedy Spring	10/28/12	70	rheocrene	1510	534314	3485254	Santa Cruz
Line Boy Spring	1/12/13	936	rheocrene	1582	529597	3466915	Santa Cruz
Little Nogales Spring	10/8/12	100	rheocrene	1421	549462	3527504	Pima
Mescal Spring	3/16/13	178	hillslope	1536	554164	3512212	Cochise

Site Name	Date	Area (m^2)	Spring Type	Elevation M	UTM E	UTM N	County
Mud Spring	6/17/12	146	rheocrene	1836	557750	3478756	Cochise
Nogales Spring	12/9/12	5000	mound-form	1402	550208	3527540	Pima
Oak Grove unnamed south	10/28/12	288	rheocrene	1502	532197	3492364	Santa Cruz
Oak Spring	6/16/12	312	rheocrene	2001	566803	3470309	Cochise
Paloma Spring	8/12/13	504		1544	545800	3475372	Santa Cruz
Papago Spring	7/12/12	333	hillslope	1572	534896	3497012	Santa Cruz
Peterson Ranch Pond	6/16/12	460	helocrene	1908	557145	3480507	Cochise
Questa Spring	6/1/12	no map		1394	529453	3522076	Pima
Ranger Station Spring	2/2/13	900	helocrene	1367	519506	3494495	Santa Cruz
Redrock South Spring Unnamed	12/27/12	420	rheocrene	1517	529594	3492547	Santa Cruz
Sansimon Mine unnamed	8/22/12	45	hanging garden	1429	528912	3488592	Santa Cruz
Sawmill Spring	5/19/12	336	hillslope	2133	516932	3510413	Santa Cruz
Scholefield Spring	5/20/12	416	mound-form	1492	526513	3525193	Pima
Silver Spring	12/8/12	no map	rheocrene	1402	550336	3527624	Pima
Smitty Spring	6/28/12	35	rheocrene	1230	546727	3532052	Pima
Sycamore Canyon Unnamed Upper	11/6/12	468	rheocrene	1062	557308	3473973	Cochise
Sycamore Spring	6/16/12	165	rheocrene	1696	557282	3473801	Cochise
Tunnel Spring	5/19/13	no map		1693	519636	3507429	Santa Cruz
Tunnels Unnamed	6/16/12	117	rheocrene	2086	567010	3470848	Cochise
Unseen Spring	10/4/13	no map		1269	543694	3528733	Pima
Upper Walker Tank Unnamed	7/1/12	80	rheocrene	1720	517321	3504134	Santa Cruz
Van Trap Spring	11/21/12	20	hillslope	1412	542117	3548845	Pima
Wakefield Spring	6/28/12	5	limnocrene	1228	547396	3532872	Pima
Walker BN Unnamed	7/1/12	no map		1836	517497	3504531	Santa Cruz
Willow Spring	3/17/13	885	rheocrene	1610	550825	3521250	Pima
Yaqui Spring	6/16/12	1	rheocrene	1741	567657	3467342	Cochise

Springs Ecosystem Assessments

The Springs Ecosystem Assessment Protocol is a framework for evaluating ecological integrity of springs, overall condition of the natural resources at springs and the risks posed by human impacts. We scored the quality and risk of 32 variables at assessed springs to evaluate ecological integrity, risk, and human impacts (Table 3). Scores range from 1 to 6 (low to high) and are assigned based on a detailed scoring rubric for the 32 characteristics (see Appendix A). It is important to note that risk scores for human impacts include the consideration of how difficult it would be to restore the site by undoing the identified human impact. Scores for *natural resources condition* ranged from 1.19 at Flux Canyon to 4.62 at Nogales Spring. Scores for *risks from human impacts* ranged from 1.41 at Tunnels Unnamed Spring to 5.1 at Aliso Spring. In general, high scores for natural resources condition corresponded with low scores for risks from human impacts. Scores for all springs are presented in Table 3.

Table 3 Springs Ecosystem Assessment Overall Natural Resource Condition and Risk Scores for Random Sample Springs

Spring Name	Aquifer Functionality Water Quality Score	Aquifer Functionality Water Quality Risk	Geomorphology Score	Geomorphology Risk Score	Habitat Score	Habitat Risk Score	Biotic Integrity Score	Biotic Integrity Risk Score	Freedom from Human Influences Score	Freedom from Human Influences Risk Score	Natural Resource Condition Score	Natural Resource Risk Score
Alamo	4.3	1.7	3.6	1.6	4.6	2.0	4.9	2.0	4.8	2.4	4.4	1.82
Apache	2.8	3.3	1.8	3.8	2.8	3.8	3.7	3.3	2.3	4.0	2.8	3.53
Baldy	3.5	2.5	2.4	3.2	3.4	2.6	3.3	2.5	3.2	2.0	3.1	2.7
Barrel	0.0		3.8	2.4	2.8	2.2	3.3	2.3	2.9	2.9	2.5	2.28
Bart												
Bear	4.3	2.0	4.0	2.2	4.6	2.4	4.1	3.5	4.8	3.0	4.3	2.53
Benton	3.8	2.0	4.0	2.2	4.4	2.2	4.6	2.4	4.1	2.6	4.2	2.19
Blacktail	4.0	2.7	3.2	3.8	3.6	2.8	3.3	3.0	3.6	3.0	3.5	3.07
Bootlegger	2.0		4.6	2.2	4.2	2.0	5.6	1.4	4.7	2.3	4.1	1.87
Burro	1.0	2.0	4.0	1.4	3.0	2.6	3.8	1.6	5.3	1.2	3.0	1.9
Chimney	3.8	1.8	3.8	3.0	4.0	2.0	5.3	2.0	5.1	1.6	4.2	2.21
Collins	2.8	2.7	2.2	2.2	4.2	3.0	2.8	3.5	3.0	2.6	3.0	2.84
Cott Tank	3.5	1.8	4.8	1.8	4.8	2.4	5.0	2.0	5.0	1.7	4.5	2.01
Cottonwood	4.0	1.5	4.0	1.8	3.4	1.6	5.0	1.7	4.9	1.9	4.1	1.64
Death Trap	4.6	1.8	5.6	1.0	4.2	1.4	3.9	2.4	5.0	2.1	4.6	1.67
Dripping	4.2	1.7	4.2	2.0	4.0	1.7	5.0	1.5	4.9	2.3	4.3	1.71
Gate	4.7	2.0	3.2	2.0	5.2	2.0	5.0	2.0	5.1	2.5	4.5	2
Happy Jack Unnamed	3.2	1.6	3.4	1.4	4.2	2.0	4.9	1.8	3.5	2.7	3.9	1.69
Hidden	0.8	3.0	2.0	3.6	2.8	3.0	2.6	2.8	2.4	2.9	2.1	3.11
Johnson	3.5	1.7	2.4	2.2	4.2	2.2	5.0	1.6	4.1	2.1	3.8	1.92
Kennedy	3.8	2.0	4.4	1.0	3.8	1.8	5.3	1.1	5.4	1.4	4.3	1.48
Line Boy	3.5	2.2	3.4	2.4	3.8	2.2	4.5	2.3	3.8	3.0	3.8	2.25

Spring Name	Aquifer Functionality Water Quality Score	Aquifer Functionality Water Quality Risk	Geomorphology Score	Geomorphology Risk Score	Habitat Score	Habitat Risk Score	Biotic Integrity Score	Biotic Integrity Risk Score	Freedom from Human Influences Score	Freedom from Human Influences Risk Score	Natural Resource Condition Score	Natural Resource Risk Score
Little Nogales	3.8	2.7	3.4	2.2	4.0	2.6	5.0	2.3	4.4	3.0	4.1	2.43
Mud	1.3	1.7	4.0	2.0	4.4	2.0	5.3	2.0	3.9	2.1	3.8	1.92
Nogales	4.2	2.5	4.4	1.8	4.8	2.4	5.1	2.3	4.9	2.7	4.6	2.24
Oak Grove unnamed south	3.7	3.0	3.8	3.0	4.2	2.4	5.0	2.6	5.3	1.9	4.2	2.76
Oak	4.3	1.8	3.4	1.5	3.0	2.3	4.0	3.0	4.4	2.3	3.7	2.13
Paloma	0.0		1.6	3.6	2.0	3.5	1.5	4.0	3.9	3.0	1.3	3.7
Papago			3.0	2.0	3.2	1.6	3.5	1.5	5.3	1.4	3.2	1.7
Peterson Ranch Pond	4.5	1.5	2.4	2.6	4.3	1.5	4.6	2.6	3.9	2.7	3.9	2.06
Ranger Station	3.2	2.5	4.4	2.0	4.4	1.4	5.3	1.7	4.4	2.1	4.3	1.89
Redrock South Unnamed	3.2	2.3	3.8	1.6	3.2	2.0	4.0	2.0	4.1	2.0	3.5	1.98
Sansimon Mine unnamed	3.3	2.0	3.8	2.0	4.0	2.6	5.3	2.0	4.4	2.9	4.1	2.15
Sawmill	4.2	2.0	3.8	2.0	4.4	1.8	4.5	2.0	4.6	1.9	4.2	1.95
Scholefield	3.5	4.5	3.2	4.6	4.2	3.4	4.9	3.5	5.3	3.4	3.9	4
Silver	0.8	2.5	4.8	2.0	3.8	2.4	4.8	2.1	4.6	2.3	3.5	2.26
Smitty	3.3	3.8	2.0	4.4	3.5	2.8	5.3	2.9	4.4	3.6	3.5	3.46
Sycamore	3.7	2.3	4.4	2.8	4.0	2.2	5.1	2.0	4.6	2.4	4.3	2.33
Tunnels Unnamed	4.4	1.2	4.6	1.4	3.4	1.8	5.8	1.3	5.4	1.4	4.5	1.41
Unseen												
Van Trap	3.0	2.2	3.0	2.4	3.0	2.4	3.8	2.6	4.9	1.9	3.2	2.4
Wakefield	3.5	2.0	4.4	2.0	4.2	2.0	5.1	2.0	4.4	2.3	4.3	2
Walker BN Unnamed												
Willow	2.0	3.0	2.2	3.0	2.2	3.8	2.4	3.1	4.0	2.7	2.2	3.22
Yaqui	3.0	2.0	3.8	1.4	1.8	1.4	5.0	3.0	3.0	1.7	3.4	1.95

To understand the main impacts that are currently decreasing the integrity of springs in the study area we examined the array of human impacts on surveyed springs (Figure 10). Flow regulation and herbivory exert the most influence on springs in the Cienega Creek study area followed closely by surface water quality and adjacent land conditions. To identify springs with potential for restoration actions or protective management actions and offer some prioritization of these, we plotted springs by overall natural resource condition and risk scores (Figure 11). We used resource condition value scores of 3 (moderate ecological condition/value) and human risk scores of 3 (moderate risk with moderate restoration potential) as the midpoints. Springs in the upper right hand quadrant are candidates for protection because they have high natural resource value but are at high risk from human impacts. Springs near the midpoint of the graphic are candidates for restoration activities because they have moderate natural resource values and are at moderate risk from human impacts. The actions to be taken would depend on site-specific conditions. See Table 4 Priority Spring Sites for Restoration or Active Management and Table 5 Priority Spring Sites for Protection for details on springs that emerged based on this analysis and careful review of on-site conditions described in the survey notes.

Figure 10: Types of Human Impacts on Springs. (High scores represent lower human impact.)

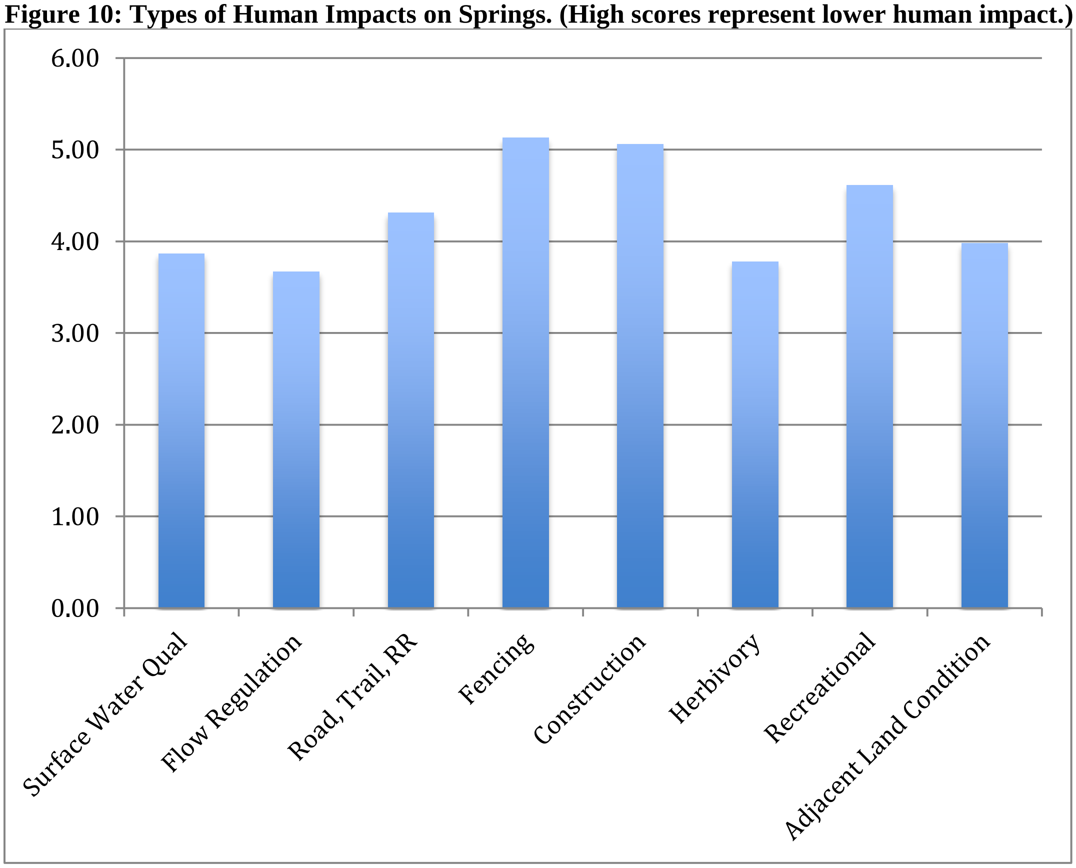


Figure 11: Stewardship Risks to Springs from Human Impacts Plotted Against Overall Natural Resource Condition. Springs in the upper right quadrant have high natural resource condition and high risk from human impacts and are candidates for protection.

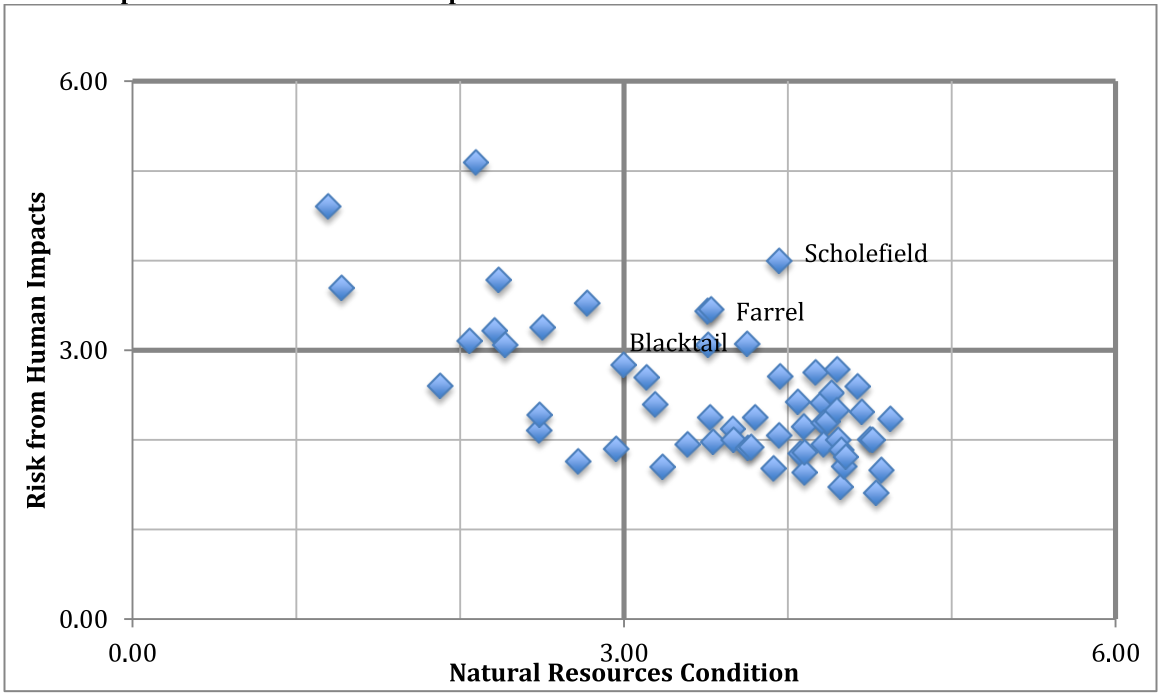


Table 4 Priority Spring Sites for Restoration or Active Management

Spring Name	Recommendations
Bear (Whetstone Mountains, non-random)	This is a heavily developed site with 100% of water being captured. The area has been degraded by cattle and there is virtually no remaining wetland habitat, aside from tanks and drinkers which are in disrepair. This site has been recommended by a regional expert as a potential restoration site. It is in a good location to expand Chiricahua Leopard Frog habitat and is historically known to have steady flow. It may be possible to pipe water to a more suitable frog habitat area down slope to re-create wetland habitat.
Benton	This site would benefit from fencing to reduce impacts from herbivory. It would be good to assess the site pre-monsoon to determine flow.
Cottonwood	The site consists of a windmill with solar panels. Water is pumping into a large tank with an adjacent cattle guzzler. The adjacent drainage has suffered noticeably. The water has also been pumped through plastic tubing all the way to and from Goat Well 2/3 mile away. Historically the spring was likely in the adjacent riparian area. The site may benefit from putting water back onto the ground in the adjacent riparian area to restore some wetted/riparian habitat, but restoration of the spring source to a more natural state does not seem likely.
Farrell (non-random)	The site has an active windmill on it which is depleting the groundwater. This water could be diverted to the channel or a flow splitter could be used; water currently overflows onto the road and does not benefit wildlife. Spring is near a proposed mine site. Historically this was a very large spring site. There is a great deal of travertine deposit at the site.
Happy Jack	The spring is located in a superfund site and may have water quality issues. It remains an important resource for wildlife, however, and habitat considerations should be addressed in any clean-up efforts. Site has very poor water quality, mining contamination is visually pervasive, and this would be a very difficult site to remediate. USFS is aware of conditions.
Line Boy	This site would benefit greatly from fencing, and access for restoration work is good. The actual spring source may be upstream of surveyed site. There is evidence of historic mining near this spot.
Peterson Ranch Pond	The pond associated with this spring is important to Chiricahua leopard frog recovery efforts. It has been infested with invasive bullfrogs in the past, and it is important that it continue to be monitored and managed to prevent recolonization by bullfrogs. An adult bullfrog was seen on the site on 7/20/13 with more calling. This is a good example site for restoration possibilities.
San Simon Mine	This site is highly altered and no longer resembles its natural state. If the permittee is no longer using the cattle infrastructure at the site, restoration of the site to a more healthy ecological condition would be valuable. Water is making its way out of the spring box and creating a nice little moist run/wetland down to the creekbed. There is a lot of water available. Access to this USFS parcel is through a private ranch.

Table 5 Priority Spring Sites for Protection

Spring Name	Recommendations
Alamo	This site has high quality habitat and should be flagged for management and protection. Ensure that grazing is managed to preserve the ecological function of the spring, or consider installation of cattle exclusion fencing.
Death-Trap	According to a local expert, this area should support mud turtles. Cows could obliterate what is left of sensitive plants, and old fencing in the area is in disrepair, so managers should determining need for and, if necessary, instal new fencing.
Gate	This site is well-protected and likely a good reference site for Rheocrene springs. There is a possibility of the water table rising since the spring was originally mapped because we located the origin further upstream of the original coordinates. Maintain exclosure as spring site appears very healthy and is showing signs of recovery. Good reference site for effects of exclosure fencing.
Little Nogales	It seems like there is the potential for OHV users to impact this site. The adjacent road should be decommissioned to prevent erosion and decrease impacts from OHV users. This spring is part of a large complex of springs surrounding Nogales Spring. It is a remote site; however, there are several roads near the site where OHV users like to ride. It is important to protect this complex of springs from damage from this type of recreation.
Nogales	This is a very high quality site with unique travertine deposits. Higher elevation travertine deposits indicate the aquifer has lowered. The presence of OHVs and adjacent roads indicates that the site would benefit from travel management. A social trail could be removed to reduce foot impact.
Sawmill	The spring is next to Sawmill Canyon Trail and is at risk of trampling by people. The development at the spring may need maintenance to maintain flow. Fire in the area has reduced the canopy cover but that may allow other species to thrive. It will be important to monitor the spring for health and continue to protect the site from grazing.
Sycamore Canyon Unnamed Upper (non-random), and Sycamore Canyon	This is a substantial and important wetland habitat in the Huachuca Mountains, and cattle should be excluded to protect aquatic and wetland species found here. There were some erosional features that were noted, but it is undetermined if these are part of the natural function of the ecosystem, or if they are of management concern. This is a likely site for Chiricahua leopard frog reintroduction. There was evidence migrant traffic at the site and some trash. Small headcuts at the site should be monitored. There were invasive crayfish at the site that would be difficult to eradicate. We recommend a re-survey for a full plant list.

Several excellent rheocrene spring sites emerged as potential reference sites, given their SEAP scores:

- **Bear Spring (Santa Rita Mountains):** Tarahumara frogs have been released here in the past indicating good ecological functioning and intact habitat. Although the site is not currently supporting Tarahumara frogs, it continues to be considered for further reintroduction efforts.
- **Cott Tank Spring (Canelo Hills):** This spring has been exclosed from grazing since 1992 and is in an area of active watershed restoration.
- **Gate Spring (Canelo Hills):** Maintain exclosure as spring site appears very healthy and is showing signs of recovery. Mining pressure in the community could negatively affect spring health.
- **Oak Grove/Unnamed South (Canelo Hills):** This site was identified by surveyors as a potential reference site due to lack of development, remoteness from human impacts and limited grazing impacts.

Because springs are so heavily altered by human uses, an important benefit of springs assessments is identifying reference sites that can inform restoration and management actions in the region.

Summary of Project Outcomes

At the close of this project we have accomplished a number of key outcomes.

Partner Engagement: Throughout the development and implementation of the project we worked with a diversity of natural resource management partners in the region to ensure we were building on existing work and creating project outcomes relevant to managers' needs. Through direct outreach and partner meetings we engaged at least 50 people representing over 20 different organizations. The following organizations have been involved throughout the project: AZGF, Pima County, USGS, USFWS, Coronado National Forest, U.S. Forest Service Region 3, BLM-Safford Field Office and Las Cienegas National Conservation Area, Saguaro National Park, NPS Sonoran Desert Network, Pima Association of Governments, the Sonoran Institute, The Nature Conservancy, Bat Conservation International, the University of Arizona Water Resources Research Center, Northern Arizona University, Arizona State University, EcoAdapt, the Desert Botanical Museum, and the Springs Stewardship Institute.

Springs Inventories: We worked with volunteers and partner organizations' staff members to inventory and ecologically assess 61 springs in the Cienega Creek study area. This includes 11 springs that were not previously mapped and three springs outside of the Cienega Creek study area as part of springs inventory protocol trainings.

Online Springs Inventory Database: We worked closely with the Springs Stewardship Institute to bring their Springs Inventory Database into an online interface that is now accessible by any interested parties at the following url: http://pinkava.asu.edu/springs/index.php.

Identification of Priority Springs for Protection and Restoration: Through analysis of springs ecological integrity assessments, we identified individual spring sites that should be priorities for protection and restoration.

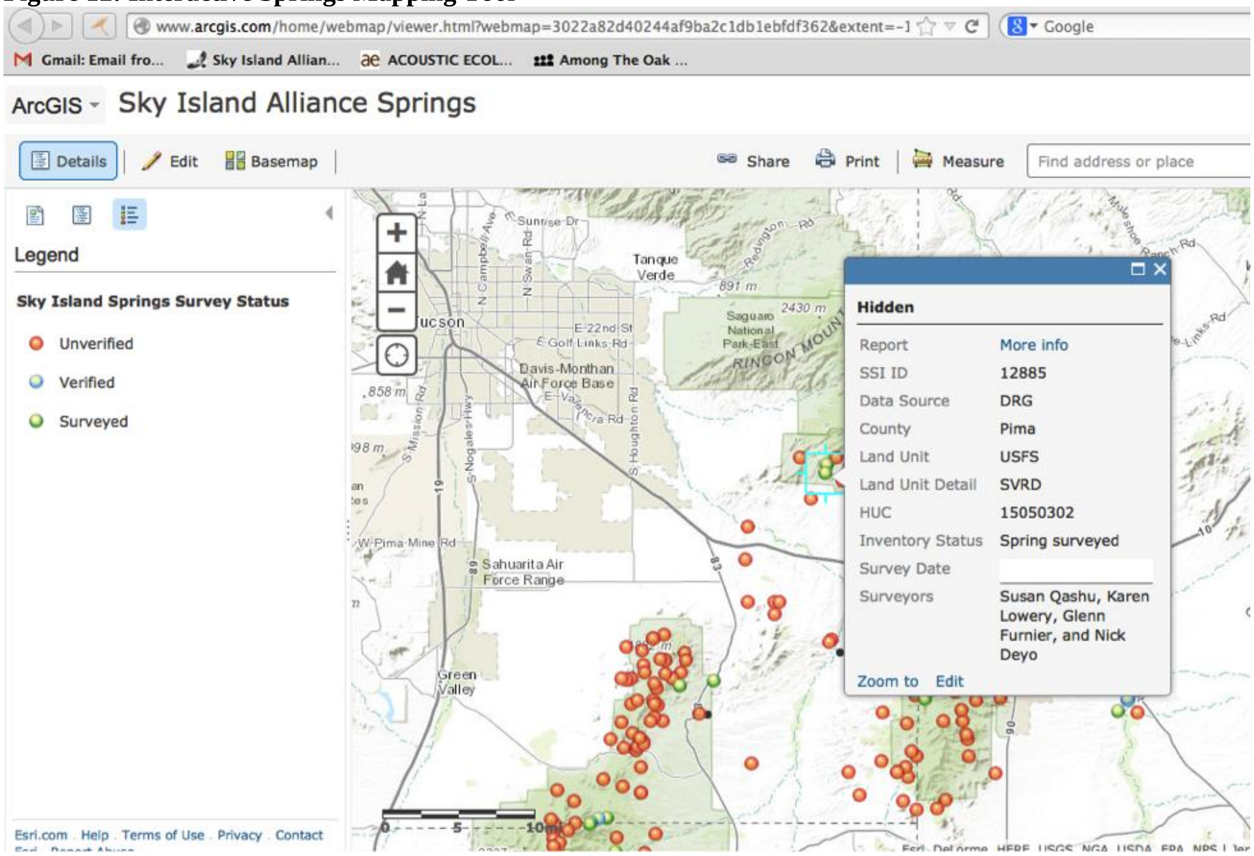
Management Recommendations and Regional Adaptation Plan for Springs Ecosystems: We conducted a climate change adaptation workshop with the regional natural resource management community in May of 2013 at which an adaptation plan was developed for springs ecosystems in the Sky Island Region (Hansen 2013). The plan identifies specific management actions to reduce the vulnerability of springs to climate change and includes specific information on partners and resources needed to implement the strategies (see Appendix C).

New Information Available and Actively Disseminated to Springs Stewards: We estimate that we have reached over 300 managers, conservationists, and scientists across the West that are stewarding spring resources. SIA staff gave oral presentations on the project methods and findings at:

- **Madrean Archipelago Conference, May 2012 (Tucson, AZ);** 300 participants
- **Climate Change Adaptation Symposium at the University of Arizona, April 2012 (Tucson, AZ)**; 20 participants
- **MntClim Conference, October 2012 (Estes Park, CO);** convened by the Consortium for Integrated Climate Research on Western Mountains; 200 participants including land and resource managers from across the west
- ***Bridging Boundaries*, October 2012 (Estes Park, CO);** hosted by the USFS Rocky Mountain Research Station, convened to highlight climate change adaptation projects for natural resource managers; 40 participants (talk available at http://www.fs.fed.us/rmrs/presentations/bridging-boundaries/)
- **DLCC Steering Committee Meeting, Fall 2012 (El Paso, TX)**
- **Climate Change Adaptation Symposium at the University of Arizona, January 2013, (Tucson, Arizona);** 15 participants
- **National Adaptation Forum, April 2013 (Denver, CO);** 450 participants
- Oral presentation given to the Regional Hydrologist for Region 3 of the US Forest Service (June 2013; Tucson, AZ)
- **Society for Ecological Restoration World Conference, October 2013 (Madison, WI);** 8,000 participants

Decision Support Tool Developed: In addition to the Springs Inventory Database we worked with the Springs Stewardship Institute to develop an online mapping application that can be accessed here http://bit.ly/1l1FqXA (note that you must zoom in once for springs to appear.) This tool allows managers to quickly navigate to geographic areas of interest and view data associated with springs (Figure 12). The user can see three levels of spring data: unverified springs that are mapped, but their status is unknown; verified springs where the locality has been confirmed; and surveyed springs where data has been collected. Reports for surveyed springs can be viewed by clicking on the spring point and accessing the hyperlinked PDF.

Figure 12: Interactive Springs Mapping Tool



Methodology for Engagement of Volunteers in Spring Inventories: We worked directly with the original authors of widely accepted springs inventory and assessment protocols (Stevens et al. 2012) to adapt the protocols for use with trained volunteers. Through the course of the project, we formally trained 31 volunteers in Springs Stewardship Institute led inventory and assessment protocols and trained an additional 69 volunteers through inventory participation. We have had strong volunteer interest and participation in the project from the start. At the close of the project volunteers contributed a total of 2,244 hours. Volunteer engagement in the project demonstrates that this type of critical baseline data can be collected by staff-led volunteer teams, which reduces costs and time investment for partner organizations that need the information to make management decisions.

Participating volunteers have expertise in plant and animal identification, hydrology, backcountry navigation, land management, and many other disciplines. Our work demonstrates a framework for accomplishing springs inventories and assessments using trained volunteers and provides an important foundation for citizen science supported monitoring of springs in the region. Involving volunteers in this work has had the positive effect of increasing the public's knowledge of and appreciation for spring ecosystems and has created support for stewardship of these resources. The following slideshows were created to attract volunteer participation in spring assessment trips, but also to provide a glimpse into the field work being conducted over the last two years.

- http://youtu.be/NIA9qY0cDC8
- http://youtu.be/AOwiTTfY6Rc
- http://youtu.be/e3ey0iaGZyY
- http://youtu.be/FCO6IReMNxs

Springs Inventory Database Described In Detail

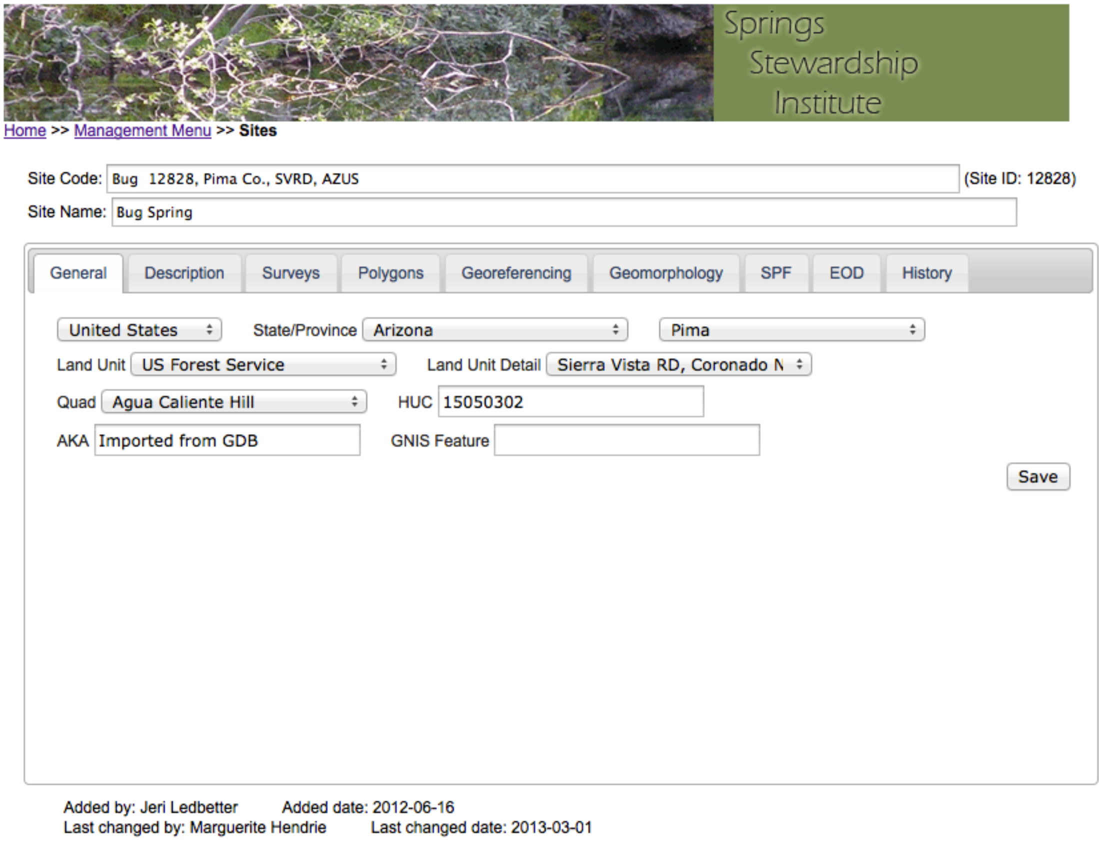
The Springs Inventory Database is a relational database originally developed in Access 2007 by Jeri Ledbetter and colleagues at the Spring Stewardship Institute (Ledbetter et al. 2010). The database serves to compile information on geomorphology, soils, geology, solar radiation, flora, fauna, water quality, flow, georeferencing, cultural resources and condition and risks, and to facilitate analysis of biological, physical and cultural relationships. The database was carefully designed to ensure that data entry does not take longer than actual data collection in the field, data entry is consistent while allowing for anomalous situations, and that information is accessible and useful once entered into the database.

The Springs Inventory Database offers a user-friendly front-end and easy methods to enter, retrieve and analyze inventory data (Ledbetter et al. 2010). The database interface directly matches the field forms (see Appendix A for field form) to allow individuals to enter field data with limited training. The database is an essential tool to store qualitative and quantitative information in order to facilitate documentation of present conditions, establish a baseline for future reference, inform the assessment process, guide monitoring, evaluate stewardship efforts, and monitor changes influenced by aquifer depletion climate change or other factors affecting an individual springs or many springs across a landscape (Ledbetter et al. 2010).

For this project the Springs Inventory Database was brought into an online interface (Figure 13) that replicates the feel and relational organization of the original database. The online version of the database is now the most up to date, living version of the database. The online database is accessible at http://pinkava.asu.edu/springs/index.php. Security of sensitive data and project specific data not yet ready to be viewed was a very important we addressed in bringing the database online. Due to the sensitivity of certain data in the database including springs on tribal lands and the location of some sensitive species, a thorough user permissions system has been developed.

User permissions will be administered by the Springs Stewardship Institute. Users of the database must first register and will then be given permissions to view and/or edit data according to their region, land management units of interest, projects of interest and other relevant categories. Once users have established permissions, they can query data, enter new data real time, and download relevant springs information as csv files for use in other applications such as a GIS. Users can also generate site-specific reports in PDF format.

Figure 13: Data Entry Interface of the Online Springs Inventory Database



The Springs Inventory Database allows for the management of a wide variety of data. This data includes general information that remains relevant for a spring regardless of when it was surveyed, such as locality information, a site description, mapping polygons, geomorphic data, solar radiation data (SPF), a measure of data thoroughness (EOD), a history of data changes, and links to associated survey data. Survey data is collected with each visit to a spring--some springs have numerous surveys associated with them. Survey data includes a description of site conditions, surveyors present, flow statistics, water quality data, flora lists, fauna lists, Spring Ecosystem Assessment Protocol (SEAP) scores, and a measure of data quality (QAQC). The following link provides a sample overview of the forms that have been developed for the spring database http://youtu.be/SRRttsdmlCQ.

Discussion

At the start of this project agencies in the Cienega Creek study area had scattered and incomplete information about springs under their stewardship. In some cases, they knew the location of springs but had no information regarding the flow rate, species supported or potential alterations of the habitat (Misztal et al. 2012). In many cases managers did not have access to information about springs on neighboring lands or across watersheds, limiting their ability to respond within a landscape and watershed context. In much of the region, lands managed by the USFS nieghbor lands managed by BLM and counties, with watersheds and groundwater basins overlapping these jurisdictional boundaries.

Information developed through this project is now available to assist managers in understanding how their springs contribute at a landscape scale. New information developed through this project is already being used in support of planning and decisions that address resource protection at the regional level and in climate change adaptation planning for natural resources. By collecting more in-depth biological and hydrological information for sites that resource managers already know the location of, we are providing a basis for understanding how environmental impacts, especially climate, are affecting these resources and for changing management to better conserve these resources.

The random sample study design of this project provided a framework for analyzing springs characteristics and overall health at a landscape-scale. It also ensured that springs chosen for survey would not be limited to well-known, or easily accessible sites and helped us avoid favoring one agency partner over another. Managers can use results from individual spring inventories to determine which priority springs are in need of immediate conservation and restoration actions. For example, Sky Island Alliance has already been looking at priority springs for restoration Table 4 and worked with the FROG Project to conduct restoration actions at Cottonwood Spring, including transplanting native aquatic vegetation for Chiricahua leopard frog habitat. As more data is collected on springs in different study areas of the Sky Island region, it will be possible to compare water quality, flow, and other parameters across study areas. This type of comparison will further inform management and improve understanding of the relationship between springs and their underlying hydrogeology.

This project will enhance long-term management and monitoring of springs ecosystems through application of methodologies for conducting inventories to train volunteers in and engage them for the long run. These methodologies and trained citizens are a strong foundation for expansion of this project and for on-going collection of data at established sites.

Given the average spring ecosystem habitat area of 464 m^2, we can expect that the 118 mapped springs in the Cienega Creek study area encompass approximately 54,752 m^2 of 4% of the entire area. Yet springs in this region have initially been documented as supporting at least 267 plant species and 123 vertebrate species. Collection of plant data was constrained by a limited number of survey team members with plant identification skills as well as some surveys being conducted during dormant periods. Collection of vertebrate and invertebrate data was also constrained by a limited number of survey team members with identification skills. There are certainly many more plant and animal species supported by springs sites in the Cienega Creek study area than were recorded through this project. However, the results of this project provide an initial sample of plant and animal diversity at these sites. This snapshot indicates that springs in the Sky Island Region are botanically rich and support high faunal diversity compared to surrounding areas.

The Sky Island Region encompasses hydrologic areas that have similar characteristics to the Cienega Creek study area examined by this project. In other areas, landownership is a similar patchwork of Forest Service (dominating higher elevations), Bureau of Land Management, State, Private and local jurisdiction lands with varying degrees of access and human use. Although each hydrologic area has unique qualities and circumstances, we would expect approximately the same level of human impacts and the same types of impacts to be occurring at springs throughout the region.

Lessons Learned

Querying managers to understand their information needs and management objectives before constructing this project proposal was key to its success. It ensured we were developing the right level of information and focusing our efforts on the right outcomes. Continued coordination with partners throughout the project has also been key to its success. This type of coordination also causes changes in approaches to management as more creative energy is focused on identifying and solving management challenges associated with springs. Springs ecosystems have risen to the forefront of conversations in the region in relation to wildlife adaptation to climate change, amphibian management, watershed restoration efforts, management planning and other topics.

Through the course of the project we identified a water quality measurement tool that is not only significantly less expensive than our original tool to purchase and calibrate, but much more accessible to volunteers and easier to carry. Moving forward we will be using the Hannah combo handheld meter for field measurements of water quality, and we will share this insight with other land managers involved in spring monitoring activities.

Volunteer surveyors were a critical component of this project. We would not have been able to complete the extensive field work without a corps of trained volunteers. This project demonstrates that in times of decreased agency resources, properly trained and led volunteers are a valuable workforce for gathering baseline information on springs. A key consideration in using volunteers as the primary work force is data quality control and protocol compliance. Because of this, we recommend that volunteer teams always be accompanied by a staff professional formally trained in assessment protocols.

Volunteer recruitment and maintenance were critical to this project. We found that planning field work to travel to high elevations sites in the summer and low elevation sites in the winter is most effective for volunteer participation. We found engaging volunteers in springs inventories to be an excellent avenue for educating the public on the importance of these waters. Our volunteer engagement model is building a community of local citizens that have an interest in understanding and stewarding springs ecosystems, and may be a powerful voice for conservation measures that will require public support.

The randomized sample design was key to developing information on springs that could be generalized to the full study area. This framework was important to ensuring that springs inventories were not limited to well-known and/or easily accessible sites but covered a diversity of springs.

In future inventory work, there is a need for volunteers with plant identification skills. This could be accomplished through targeted training of volunteers in plant identification. It could also potentially be addressed by coordinating more effectively with organizations like the Arizona Native Plant Society or with our agency partners to get professional assistance on surveys.

Management Recommendations

Ecosystem functioning of springs in the study area was most disrupted by flow regulation and herbivory, followed by surface water quality and adjacent land conditions.

Management options to address flow regulation include:

- maintaining current infrastructure so that water is not wasted or lost;
- removing infrastructure that is no longer in use to allow water to support wetted habitat;
- modifying flow regulation structures so that water is available to wildlife in addition to the use it is regulated for; and
- splitting flow regulation or otherwise putting some water onto the land to support wetted habitat while still keeping some water regulated for the intended use.

Management options to address herbivory include:

- removal of non-native grazing as a land use in areas with high value and sensitive springs ecosystems;
- fencing to exclude cattle from springs entirely;
- fencing and flow regulation modification to exclude cattle from springs microhabitats while still allowing them access to drinking water; and
- modification of grazing management to decrease disturbance that may decrease biological diversity and to give the area longer recovery time.

Management options for addressing impacts to surface water quality include:

- the management options described above to manage herbivory which would reduce trampling and erosion;
- modification of neighboring roads and trails to ensure they are not causing erosion that is decreasing surface water;
- addressing underlying water contaminations issues (e.g. mine site clean up); and
- addressing adjacent land conditions to prevent catastrophic fire and other erosion-causing events.

Management options for addressing adjacent land conditions include:

- active post-fire restoration to address erosion due to fire;
- modification of grazing in adjacent lands to allow for vegetation re-growth and diversification;
- decreasing erosion associated with trampling; and
- other watershed management actions to maintain and restore healthy landscapes that will decrease threats of erosions and increase infiltration of water.

Many of the above described management options are within the reach of land managers in the Sky Island Region. They can be implemented through other initiatives occurring in the region. Key initiatives include district-wide watershed restoration activities, FireScape and the Pinaleno Ecosystem Restoration Project currently being led by the Coronado National

Forest, endangered species recovery for the Chiricahua leopard frog being led by the AZGF and USFWS, and landscape restoration efforts being led by the BLM, particularly on the Las Cienegas National Conservation Area. The Coronado National Forest is currently revising its Land and Resource Management Plan, which provides an opportunity to begin codifying special protections for springs that are in moderate to excellent ecological condition. It also provides an opportunity to prescribe management direction for springs that are actively being managed for human uses that will support adaptation to climate change for springs ecosystems and wildlife.

Project Benefits and Next Steps

Leveraging Desert Landscape Conservation Cooperative Resources

We were able to leverage the original funding provided by the DLCC and BOR WaterSMART grant to secure the following additional resources:

- A two-year grant from the Doris Duke Charitable Fund's Climate Change Adaptation Fund (administered by The Wildlife Conservation Society) to rehabilitate or restore 9 priority spring sites in the Sky Island Region to support adaptation of wildlife to climate change.
- A two-year grant from the Nina Mason Pulliam Charitable Trust to assess springs affected by fire, develop an Arizona Springs Restoration Handbook and integrate springs assessment findings into management planning.

Recommended Next Steps

Through this initial round of springs assessments and adaptation planning with regional managers, we have identified, and are actively working on a number of next steps that will enhance stewardship of springs resources in the Sky Island Region.

1. **Train managers, researchers, and conservationists in the use of the online Springs Inventory Database.** Although the database is user-friendly, active training of database users will enhance effective use of this powerful tool and will also serve as a way to encourage potential users in the region to incorporate their data into the database.
2. **Develop site specific management plans for springs** that are emerging as high priority ecosystems in the Sky Island region.
3. **Collect more site specific information on springs** to continue to build baseline information on individual sites and inform management.
4. **Collect new springs inventory information in different hydrogeologic areas of the Sky Island Region** and compare parameters and characteristics across different areas to better understand the function of springs at the landscape level.
5. **Develop seasonal monitoring methods and program for springs.** Seasonal monitoring of springs has emerged as an important aspect of understanding and tracking changes in springs ecosystems. This is necessary to truly understand the full suite of flora and fauna supported by a spring, to detect seasonal fluctuations in flow, and to detect long-term changes in flow volume. It will also inform any

potential future restoration. Because managers have limited resources for field monitoring, we recommend that the volunteer-driven inventory model be expanded to include an Adopt-a-Spring seasonal monitoring aspect. Volunteers already trained in springs inventory protocols could be trained in seasonal monitoring protocols and could visit key springs site (potential restoration or reference sites) over the course of 5 desert seasons throughout the year collecting data on flow, flora, and fauna. That information could then be related back to local precipitation and management context information.

6. **Develop an Arizona Springs Restoration Guidebook to bring together expertise and information on restoration options.** This Guidebook would include decision-support information on springs ecology, restoration options, biological and ecological considerations, regulatory and administrative considerations, tribal considerations, and illustrative case studies of springs restoration efforts in Arizona.
7. **Develop a Sky Islands Wetland and Riparian Plant Identification Guide.** Throughout the assessment process, botanical knowledge was identified as a limiting factor; wetland species in arid regions are not always widely known, even amongst native plant enthusiasts. There is no specialized botanical guide for these important habitats for the Sky Island Region. This type of guide would be invaluable for use in springs inventories in the region and would at least partially address the need for improved botanical record collection at springs inventories. It could also be a component of the Restoration Guidebook. This guide could include highlights of sensitive or particularly important wetland associated plants that surveyors should be on the lookout for, possibly by mountain range, watershed or some smaller landscape unit to facilitate use. Use of the Southwest Environmental Information Network (SEINet; http://swbiodiversity.org/portal/index.php) and Madrean Archipelago Biodiversity Assessment MABA (http://www.madrean.org/symbflora/) online databases would allow such an effort to be constantly updated and refined so that users could compile regional or specific field guides for the area they are working in.
8. **Expansion of the effort into the Mexican portion of the Sky Island Region.** The dearth of information on springs in the US portion of the Sky Island Region is clear; this lack is even more pronounced in the Mexican Sky Islands. It is impossible to accurately assess the condition of springs throughout the region without a matching effort in Mexico. Many of the region's most-important waterways (the San Pedro and Santa Cruz rivers, for instance) have bi-national watersheds.

References Cited

Anning, D.W., and Konieczki, A.D., 2005, Classification of hydrogeologic areas and hydrogeologic flow systems in the Basin and Range Physiographic Province, Southwestern United States: U.S. Geological Survey Professional Paper 1702, 37 p.

Brown, D.E. and C.H. Lowe. 1981. Biotic communities of the Southwest, map (1:1,000,000). Gen. Tech. Rep. RM 78, U.S.D.A. Forest Service, Fort Collins, CO.

Hansen, L. 2013. Adaptation Action Plan For Springs Ecosystems from *Learning to Live with the Heat: Adapting to a Changing Climate in the Sky Island Region.* Sky Island Alliance. 8 p. Accessible at http://www.skyislandalliance.org/adaptationworkshop2013.htm

Ledbetter, J.D., L. Stevens and A.E. Springer. 2010. Springs Inventory Database. 34 p. Accessed at http://www.springstewardship.org/PDF/BrochureText060411.pdf

Misztal, L. 2011. Climate Change Adaptation in the Arid Southwest: A Workshop for Land and Resource Management Workshop Summary Report. Sky Island Alliance. 42 pp. Accessible at http://www.skyislandalliance.org/adaptationworkshop2010.htm

Misztal, L.W., L. Hansen, and G. Garfin. 2012. Responding to climate change impacts in the Sky Island Region: From planning to action. In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrean Archipelago III and 7th Conference on Research and Resource Management in the Southwestern Deserts; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 60-67.

Meinzer, O.E. , 1923. Outline of Ground-water Hydrology, with Definitions. U.S. Geological Survey. Water Supply Paper 494.

Perla, B.S. and L.E. Stevens. 2008. Biodiversity and productivity at an undisturbed spring, in comparison with adjacent grazed riparian an upland habitats. Pp. 230-2243 *in* Stevens, L E. and V. J. Meretsky, editors. 2008. Aridland Springs in North America: Ecology and Conservation. University of Arizona Press. Tucson, AZ.

Powell, Brian. 2011. Inventory and Status of Unsupplemented and Perennial Surface Water on Pima County Open-space Properties. Pima County Office of Sustainability and Conservation. 12 pp.

Solar Pathfinder, Inc. 2012. Solar site analysis Linden.

Springs Stewardship Institute. Accessed 12/12/13 at http://www.springstewardship.org/arizona.html.

Springer, A.E. and L.E. Stevens. 2008. Spheres of discharge of springs. Hydrogeology Journal DOI 10.1007/s10040-008-341-y.

Stevens, L.E., H. Kloppel, A.E. Springer, D.W. Sada. 2006. Terrestrial Springs Ecosystems Inventory Protocols Narrative. *Revised 4/20/06.* National Park Service Cooperative Agreement Number CA 1200-99-009. 45 pp.

Stevens, L E. and V. J. Meretsky, editors. 2008. Aridland Springs in North America: Ecology and Conservation. University of Arizona Press. Tucson, AZ. 406 pp.

Stevens, L.E., J.D. Ledbetter, and A.E. Springer. 2011. Inventory and Monitoring Protocols for Springs Ecosystems. 56 pp. Accessible at http://www.springstewardship.org/PDF/Springs_Inventory_Protocols_110602.pdf

Stevens, L.E., J.D. Ledbetter, and A.E. Springer. 2012. Springs Inventory and Assessment Training Manual, Version 2.01. Springs Stewardship Institute, Museum of Northern Arizona.