Inventory, Assessment, and Stewardship of Springs Ecosystems through Geocollaboration

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Introduction

Springs—hydrologic features where groundwater reaches, and usually flows from the surface—are among the most biologically diverse habitats. Particularly in arid regions where springs are isolated by harsh surrounding landscapes, springs are islands of habitat that support high biodiversity and endemism (Stevens and Meretsky 2008). Yet these sometimes tiny features are inadequately protected, poorly mapped, and insufficiently understood. The Springs Stewardship Institute (SSI) has developed collaborative online tools to enable land managers, conservation organizations, and researchers with limited resources to coordinate efforts to identify and protect springs, as well as to improve understanding of these complex ecosystems.

Figure 1. Survey of Lockwood Spring in Coconino National Forest, Arizona.

Background

Afforded little legal protection, springs ecosystems are widely exploited by humans through diversions for potable and livestock water, irrigation, and mining, and from recreational activities (ibid). Many springs have been obliterated by construction of roads and buildings, or are trampled by expanding populations of non-native animals. Invasive plants and animals often overwhelm native species, disturbing springs ecological health. Excessive groundwater pumping from aquifers depletes or dewaters springs, and climate change may profoundly affect flow. As a result of these impairments, relatively few springs ecosystems remain intact.

Relatively little is known about springs ecology. Although much time and funding has been devoted to understanding and protecting wetlands, streams and aquifers, there has been little research about a critical link between these resources—where water from aquifers reaches the surface to form streams and wetlands (Nabhan 2008). Some research has focused on individual springs. Dean Blinn of Northern Arizona University conducted comprehensive research on the unique ecology of Montezuma Well in Arizona (Blinn et al. 1982, Runck and Blinn 1994, Wagner and Blinn 2000, Blinn 2008). There has been much research on Devils Hole spring in the Ash Meadows National Wildlife Refuge of Nevada, primarily because it supports an endangered endemic species, the Devil's Hole pupfish (Landwehr 2004). Some researchers have included springs along with studies of other water resources, such as streams, lakes, and ponds (Brown and Moran 1979, Grand Canyon Wildlands Council 2004). Yet although springs provide base flow for many of the world's streams and rivers, and often are the source of water for ponds and lakes, springs ecology fundamentally differs from other aquatic habitats. Therefore, springs require different inventory, assessment, and restoration methods. Most studies of springs across landscapes focus on a single characteristic, such as water chemistry, groundwater modeling, or geomorphology (Flora 2004, Rice 2007, Hallam 2010). Donald Sada has conducted extensive research on aquatic desert ecosystems of the Great Basin and Mohave Desert. Although some of his work included a wide range of biota (Sada and Nachlinger 1996), much of his work focused on endemic springsnails (Sada 2008a and b). Williams et al. (1997) examined the relationship between water chemistry and macroinvertebrate communities at 20 springs in Ontario. Springer and Stevens (2008) identified and described 12 spring types, classified by geomorphic characteristics. Krezic (2010) published a book focused on springs hydrology with many hydrologic and management anecdotes, but gave virtually no attention to springs ecology.

Although there have been several landscape-wide springs inventories in North America, such data are limited. Gunnar Brune (1981) conducted an inventory of springs in about half of the counties in Texas, including location, name, and general information about the sites. The Wisconsin Geological and Natural History Survey completed an exhaustive inventory of Wisconsin's springs (Macholl 2007). This notable effort produced a database with 10,851 features, but with a limited array of data. Scott et al. (2004) inventoried springs of Florida, but restricted their research to the hydrology and geochemistry of limnocrene (pool-forming) spring types. Similar efforts have been made for Missouri (Vineyard and Feder 1982), and Alberta (Borneuf 1983). The Alberta Geological Survey (2009) released a shapefile of the province's springs, although the layer is missing many known springs across this semi-arid region.

Until recently there has been no systematic effort or methodology to survey and assess the physical, chemical, and biological characteristics, and the ecological status of springs across a landscape. What little information exists is fragmented and largely unavailable to researchers, land managers, and conservation organizations.

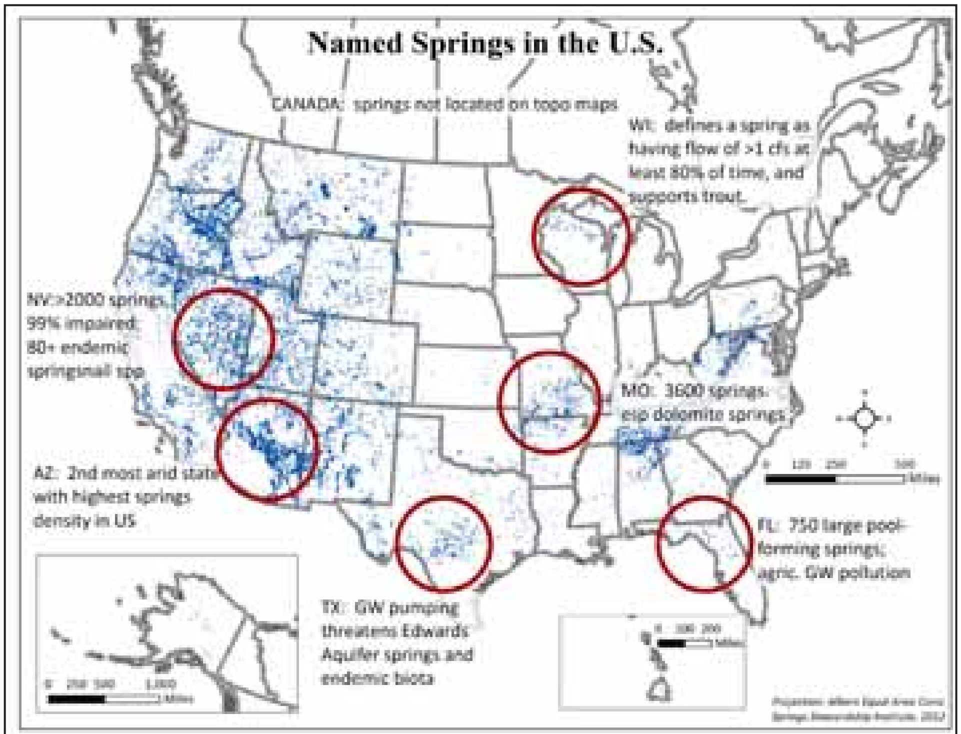

Figure 2. Named US Springs (GNS 2012). Produced using ArcInfo©, contributed through the ESRI ECP Conservation Grant Program, used here for educational purposes only.

Stevens et al. (2011) developed Springs Inventory Protocols to efficiently survey and assess springs. They describe a comprehensive protocol for evaluation of the ecological health of springs that includes geomorphology, soils, geology, flora, fauna, water quality, and flow, as well as a thorough qualitative assessment of the site's condition and the risks to the ecosystem. Subsequently the US Forest Service (2012) published inventory field guides for survey of groundwater-dependent ecosystems that were loosely based on the work of Stevens et al. Several units of the National Park Service have made an effort to conduct regional surveys of springs. Other agencies are contemplating similar programs. However, these efforts lack a collaborative approach; this results in duplication of effort and largely incompatible data collection protocols.

In spite of the critical importance of water, in both arid and moist regions worldwide, many springs remain unmapped. In the arid desert Southwest, the number of springs is unknown; it is likely that thousands are not mapped, particularly in the most remote regions. In many US states, where hydraulic fracturing threaten groundwater, there is no complete map of springs that could be affected. Throughout the United States, human activities threaten springs ecosystems (Figure 2).

Springs can only be protected if land managers know where they are located, understand how they function, and know their condition. The goal of this project is to better coordinate data collection methods, to compile available information, and to make this information accessible to land managers, conservation organizations, and other researchers through geocollaborative tools. The dearth of knowledge regarding springs represents a global challenge, and SSI's work is international in scope. Here we present our efforts to survey and assess the ecological condition of springs of Arizona.

Arizona Springs

Arizona, America's second-driest state, likely contains the highest density of springs. The total number of springs is unknown. Although several point feature layers exist for the state, none are complete and each contains features not included in the others (ALRIS 1993, AGIC 2008, USGS 2010). Springs are non-randomly distributed, clustered along escarpments such as Grand Canyon in northern Arizona, and the Mogollon Rim in the center

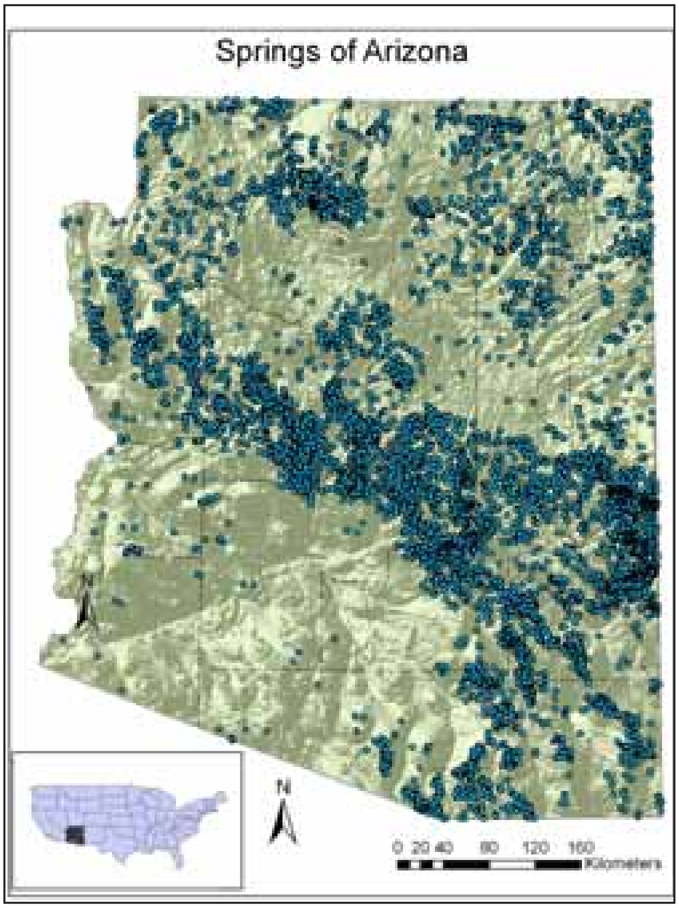

Figure 3. Compilation of available data for 9132 Arizona springs, as of June 2012. Data provided by federal and state governmental organizations, Tribal governments, conservation organizations, and individual researchers. Layers acquired from governmental organizations include ALRIS (1993 & 2008), Coconino National Forest (2009), and the Southern Colorado Plateau Parks Network (2010). Contributing conservation organizations include Grand Canyon Trust, Grand Canyon Wildlands Council, and the Museum of Northern Arizona. Individual contributors include Brown and Moran (1979), Glenn Rink, Larry Stevens, Jeri Ledbetter, Abraham Springer, Steve Monroe, and Steve Flora.

of the state (Figure 3). SSI has compiled springs locality data from many sources, including land managers, Tribal governments, conservation organizations, and individual researchers.

Springs in Arizona are poorly protected and heavily influenced by humans. A study by Grand Canyon Wildlands Council (2004) of springs in Northern Arizona determined that more than 82% suffered ecological impairment. Even in relatively protected areas, such as Grand Canyon National Park, nearly 70% of springs were impaired.

Several recent studies have contributed greatly to understanding of springs ecology in this arid state. Flora (2007) collected flow data for springs of Central Arizona, Rice (2007) used springs as indicators of drought, and Hallum (2010) identified a positive relationship between geomorphology and plant diversity. The US Forest Service Four Forest Restoration Initiative (4-FRI) has led to increased interest in springs ecology (Springer 2010). However, the ecology of Arizona springs remains poorly understood.

The need for comprehensive inventory and assessment of springs is increasingly recognized. Although several agencies, conservation organization organizations, and individual researches have conducted studies of Arizona springs, collaboration has been limited.

Inventory and assessment of springs, particularly within rugged and/or remote terrain, is costly, requires considerable effort, and presents significant logistical challenges. Development of a collaborative approach and consistent methodology among those working toward locating, surveying, and monitoring springs maximizes available resources and reduces duplication of effort. This project is increasing our ability to better understand and protect these fragile and irreplaceable resources.

The primary goal of this project is to provide an efficient, cost-effective technological framework to support geocollaborative scientific efforts and conservation planning among local watershed and conservation groups, Indigenous Tribes, researchers, and agencies.

Methods

The tools developed to achieve this goal include published protocols and other educational materials available at SpringStewardship.org, a relational Springs Inventory Database with a user-friendly interface, online access to data, and interactive maps.

Much of the information gathered during a springs survey is sensitive, as springs ecosystems often provide habitat for endemic, threatened, and endangered flora and fauna. Springs are often associated with cultural and historic sites, and are considered extremely sacred to many Indigenous cultures. Efforts to share information must be carefully balanced with protecting sensitive information.

Springs Inventory Database and Geodatabase

We have designed the Springs Inventory Database to facilitate survey data entry following the Springs Inventory Protocols developed by Stevens et al. (2011). The information collected in each category is complex, and many of the data are interrelated. The database provides a relational framework to contain these data, and to analyze the biological, physical, and geospatial interrelationships associated with springs (Figure 4).

In 2008 we designed Version 1 of the database using Microsoft Access© 2007. We selected this software because of its ubiquitous availability and relatively low cost for academic and non-profit use. Over the next several

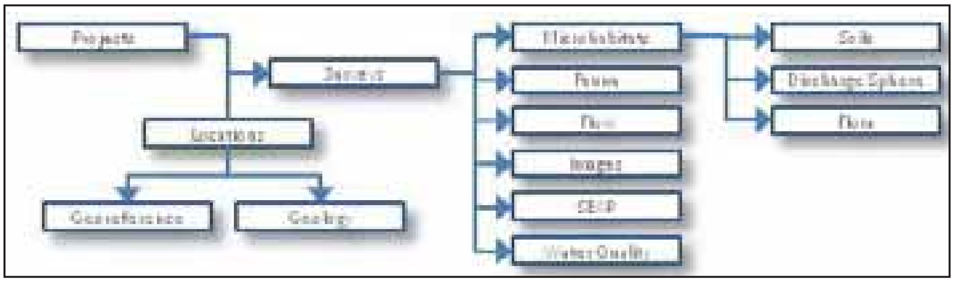

Figure 4. Relationship of primary tables in the Springs Inventory Database, designed using Microsoft Access©.

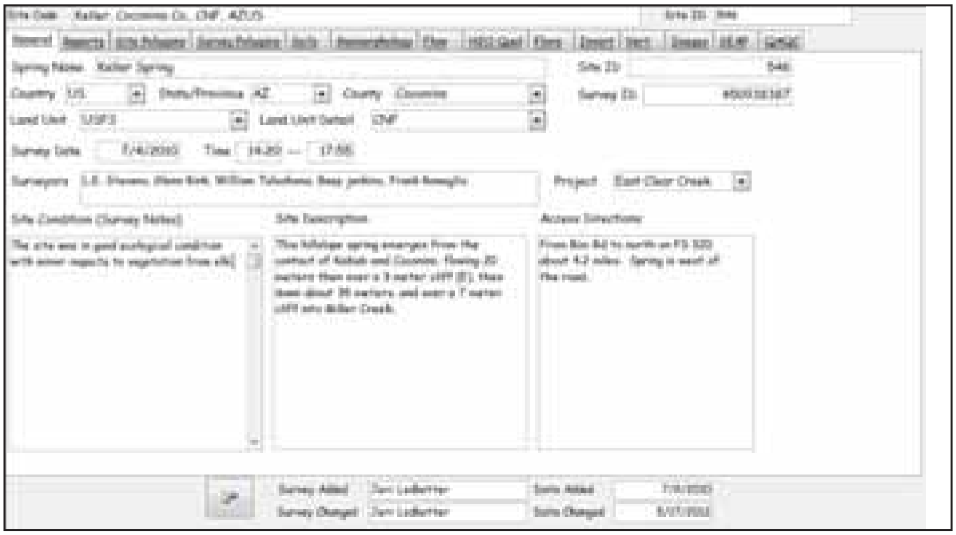

Figure 5. Screen image of user interface of the Springs Inventory Database displaying the survey form. Interface was designed using Microsoft Access©.

years, we entered data from several hundred springs surveys. During this time, based on what we learned from conducting the surveys, we refined the protocols as well as enhanced the database design.

A user-friendly front end interface (Figures 5, 6, and 7) links to a back end file that contains the survey data. Location data are contained in a separate ESRI personal geodatabase, joined using a common site code. This enables geospatial analysis of a vast and steadily growing amount of survey data.

The database interface is designed to match the field sheets completed during the surveys. This allows a non-expert with little knowledge or experience to enter data quickly and accurately. Its structure assures consistency (for example, using look-up tables) while still providing flexibility for anomalous situations.

The primary tables and relationships between them, the foundation of

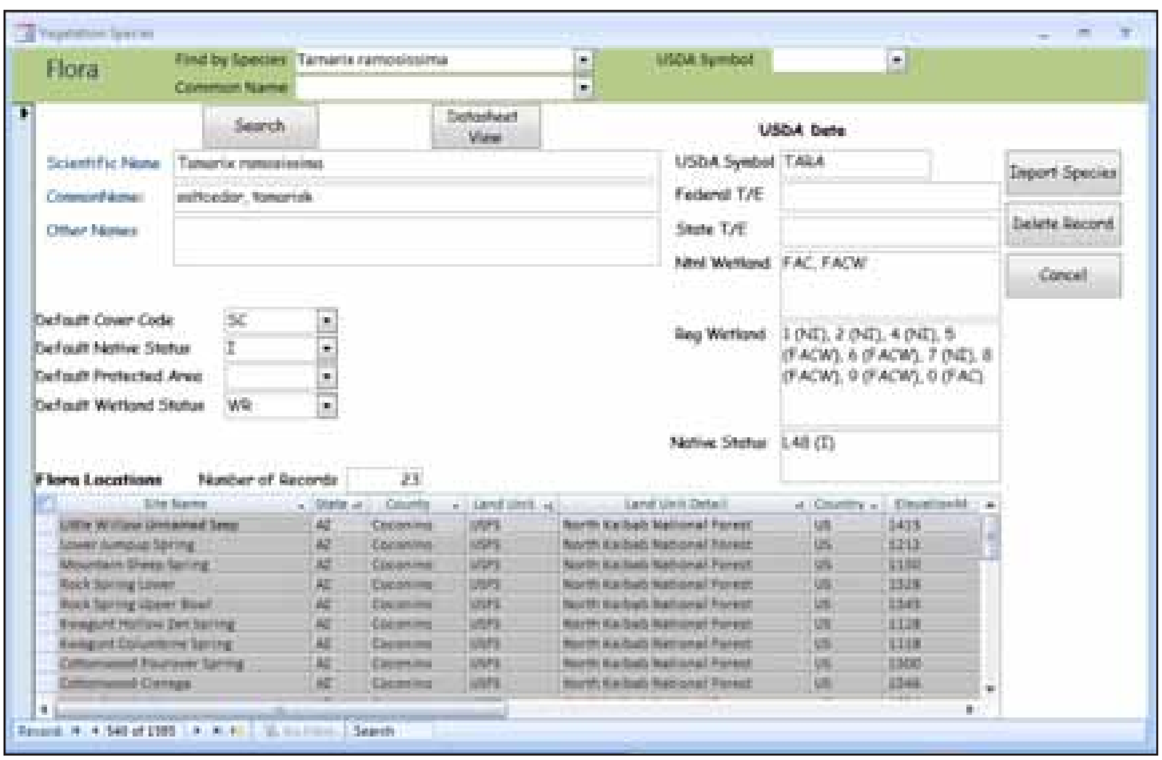

Figure 6. Screen image of vegetation form from the Microsoft Access© Springs Inventory Database. This form displays each site where a particular species has been reported. The database can provide information on distribution of sensitive or rare species, as well as nonnative vegetation.

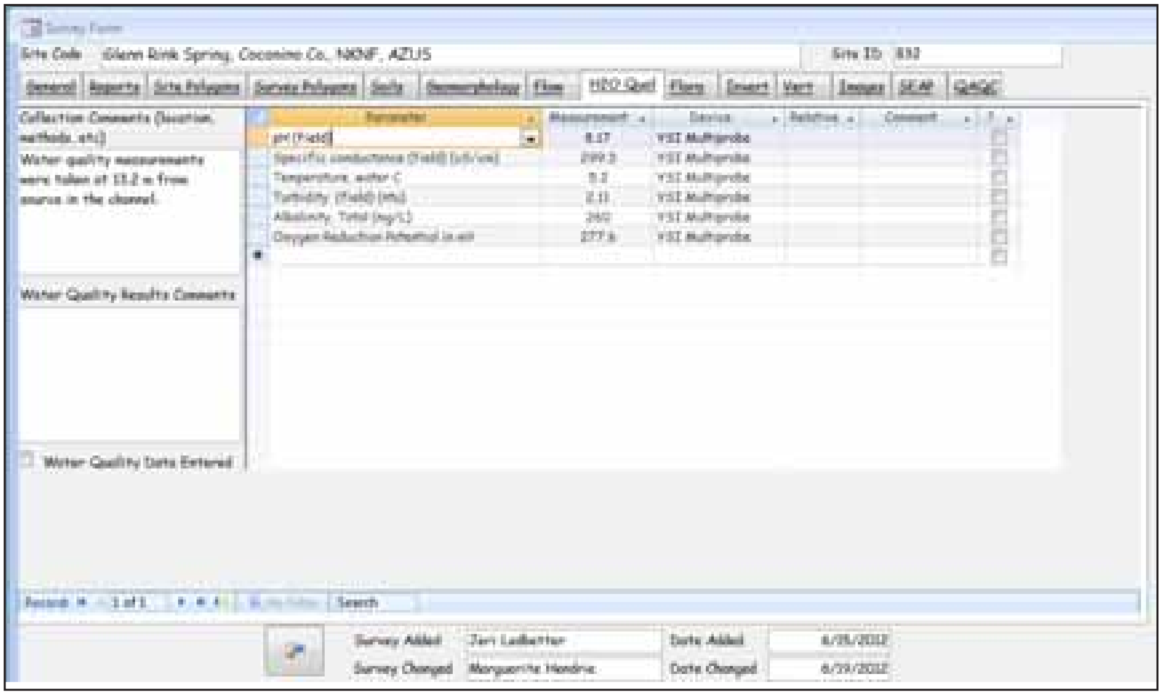

Figure 7. Screen image of water quality data entry form. Water quality characteristic names are consistent with EPA's Storet.

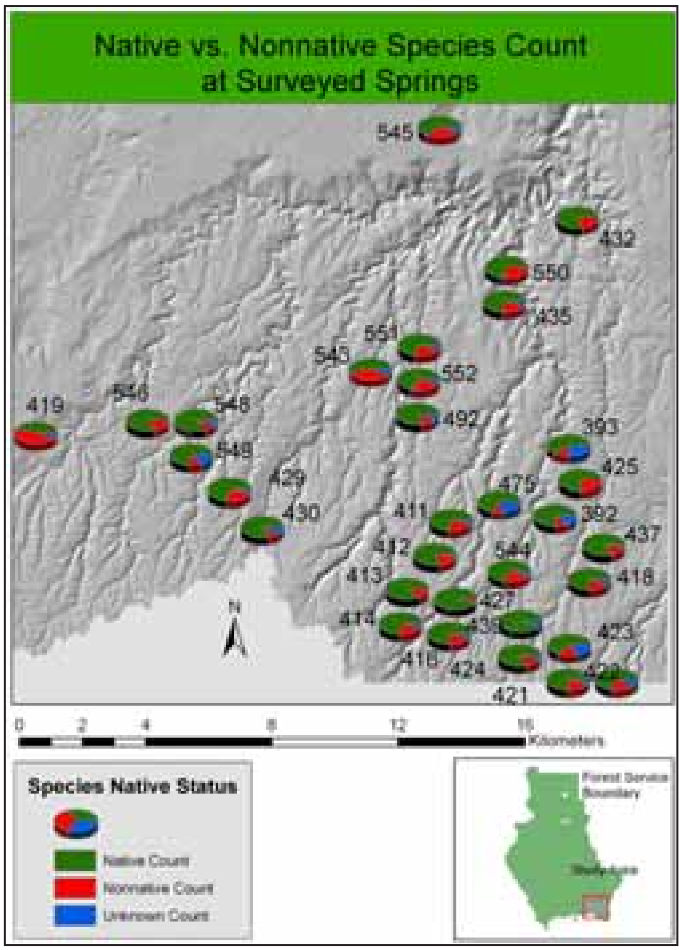

Figure 8. Analysis of native status of vegetation at springs in Coconino National Forest, generated by joining the Springs Inventory Database with the Arizona Springs Geodatabase. Produced using ArcEditor©, used here for educational purposes only.

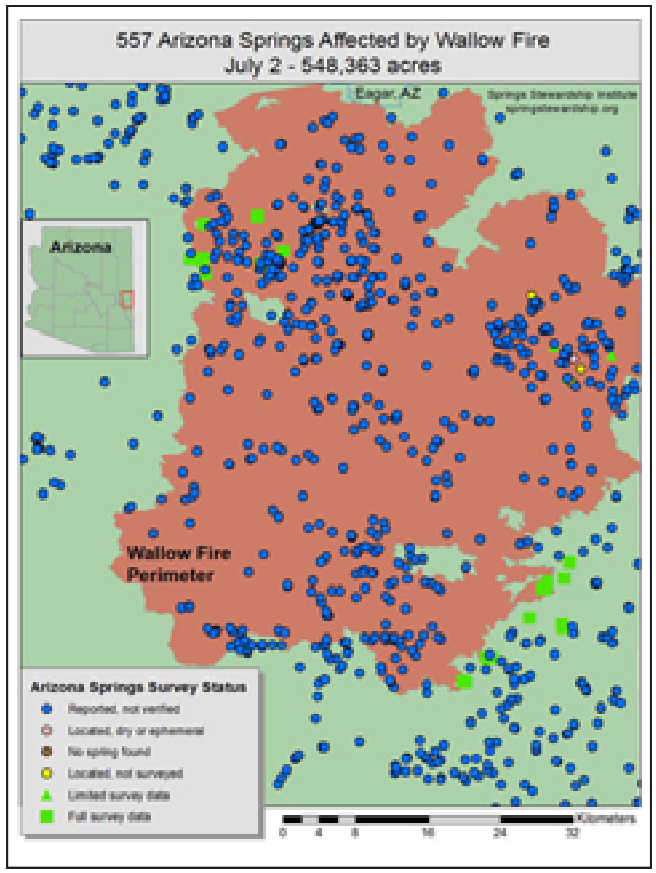

Figure 9. Analysis of springs affected by the Wallow Fire that ignited on July 2, 2011, burning over 500,000 acres in western Arizona. Unfortunately, SSI surveyed only a few of these springs prior to the fire. Fire perimeter provided by the US Forest Service. Map was produced using ArcEditor©, used here for educational purposes only.

a relational database, allow users to query and export meaningful data, reports, and maps (See Figures 8 and 9).

Although the Microsoft Access database and personal geodatabase system worked well across our local network, it did not lend itself to collaboration. We could only provide land managers and partners with snapshots of the information. Entering, querying, and exporting data was only possible in our small office. As we began to collaborate with researchers in other parts of Arizona, across the region, and in Canada, we needed to develop a way to better share springs data.

Migrating Spatial Data to the Cloud

Using an Amazon Web Services Elastic Compute Cloud (EC2) instance established by Pennsylvania State University, (PSU) we migrated the Arizona Springs geodatabase to SQLServer Express, and published it to a mapping service. PSU provided an initial credit that covered fees during the initial design phase. Although EC2 offers a reliable way for small organizations to publish GIS data in the cloud with no up-front costs, expenses can accrue significantly at Amazon's standard rate. Rates depend upon the size of the datasets and demand. We have applied to the ESRI Conservation Grant program (ECP) for Amazon Cloud access to ArcGIS Server in order to reduce this cost. ECP has already generously supported our work through donations of software and training.

We have published springs maps for several forest service units in Arizona. Access to these maps is restricted to members of the Springs Stewardship Institute on ArcGIS Online due to the sensitivity of the information. With permission, land managers, conservation organizations, and collaborators can access survey data using the relatively simple user interfaces available through ArcGIS Online (Figure 10). Users can click on a spring to open a pop-up, and click a hyperlink to open a full survey report. This is an 8-page PDF that contains photos, sketchmaps, and all survey data collected at a site (Figure 11). It is automatically generated from the Springs Inventory Database and saved on the Springs Stewardship Institute website.

Migrating the Database for Online Access

Working in collaboration with the Sky Island Alliance, SSI has begun to migrate the Springs Inventory Database to also make it accessible in the cloud and online. We have migrated the back end file to MySQL tables on a remote server. We will continue to use the Microsoft Access front end interface; this will require some redesign and additional coding. Once the migration is complete, collaborators will be able to download the front end interface file, and link to the MySQL tables on the remote server.

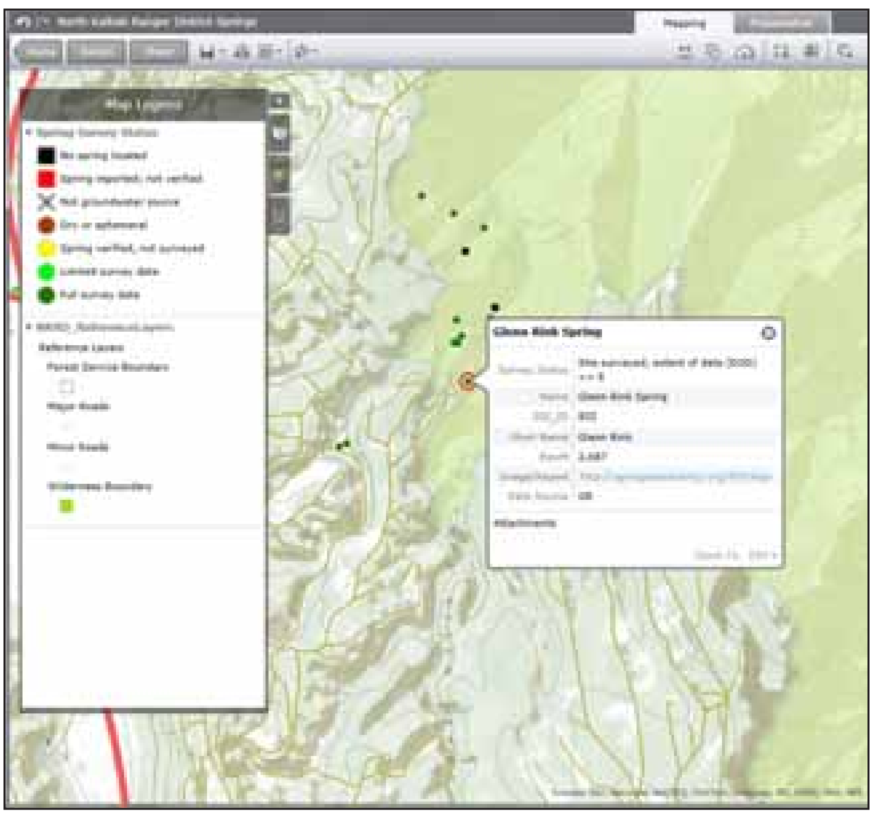

Figure 10. Screen image ArcGIS Explorer Online displaying a springs map of North Kaibab Ranger District on the North Rim of Grand Canyon. This interface accesses a web maping service published using an Amazon Web Services instance. Land managers, collaborators and researchers can access survey data through this relatively simple interface.

We are also developing a portal that will allow users to access the MySQL tables through a web interface. Although this will not provide full functionality of the database, it will enable researchers, land managers, and conservation organizations to query available data, and to enter a limited amount of data.

Once the database migration is complete, it will link to the geodatabase using a common Site ID with a one-to-one relationship. This will to provide the capacity for geospatial analysis and generation of map products among collaborators.

SSI is currently working within many land units throughout the state, including national forests, Native Tribal lands, National Parks, and private land. Securing sensitive cultural and private information, as well as sensitive species information, is our greatest challenge during the design phase. We are developing a set of access levels, from read-only to design status, in combination with limiting access based on land ownership, in order to protect sensitive information as well as the data.

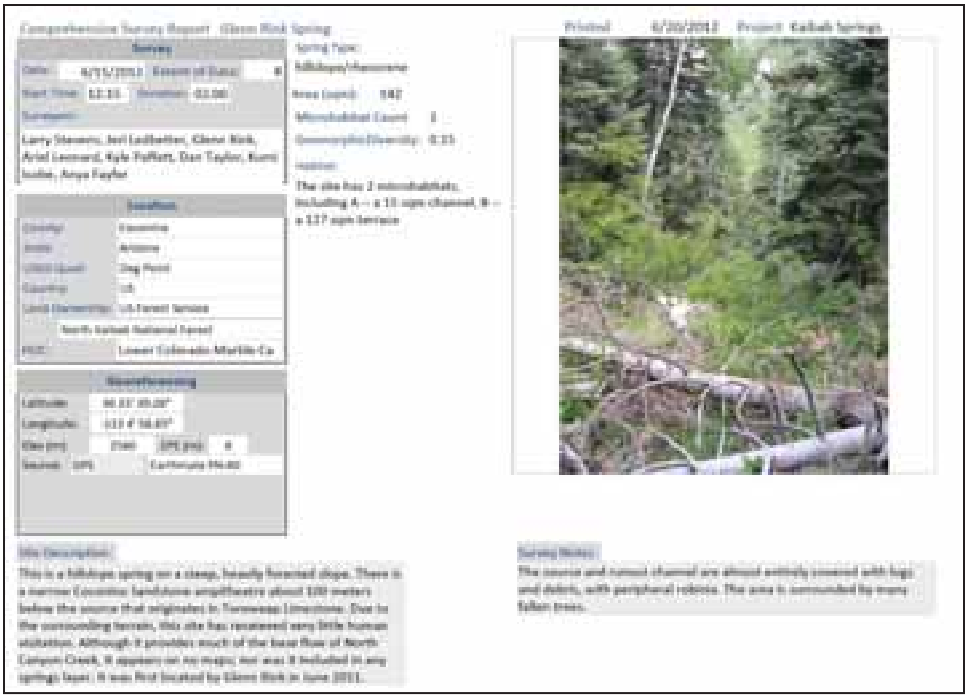

Figure 11: First page of an 8-page comprehensive report with survey data. The report contains all data collected at a site, including images, flora, fauna, water quality, flow, a general description, and assessment data. This report is generated from the Springs Inventory Database, and available online at springtewardship.org.

Volunteered Geographic Information

SSI has developed a "Hide and Seep" Volunteered Geographic Information (VGI) program to engage the public in the effort to locate additional unmapped springs. This citizen science program is accessible on the SSI website at http://springstewardship.org/play.html, and at ArcGIS Online. In the future it will be available as a mobile application.

Conclusions

Springs ecosystems are biologically and culturally important, and enormously threatened. Yet they are poorly understood and incompletely mapped. The Springs Stewardship Institute is committed to developing geocollaborative technologies that promote springs research, and to making them broadly available to other researchers, land managers, and conservation organizations. This effort will increase our understanding of springs ecology, distribution, and status, as well as reduce duplication of effort. The methodology described here will allow a small organization to cost-effectively publish data in the cloud, enabling sharing of resources and information. By first developing these technologies to support research in Arizona, we will demonstrate how they can be applied to springs in other climates, and throughout the world.

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Acknowledgements

None of this work would have been possible without the support, advice, ideas of many people who inspired us to continue this work. Megan Souter entered much of the survey data, with admirable attention to detail. Marguerite entered data, participated in surveys, and helped to develop the springs geodatabase, enduring the tedium of resolving duplicates and cleaning up the raw data. Dr. Abe Springer of Northern Arizona University also provided invaluable support, advice, and student interns.

Kaibab National Forest provided significant funding in support of data compilation and surveys through the Museum of Northern Arizona. Funding from the Nina Mason Pulliam Charitable Trust supported additional surveys with volunteer partipation.

We deeply appreciate the collaboration of Grand Canyon Wildlands Council, Grand Canyon Trust, and Steve Monroe of the Southern Colorado Plateau Network, who contributed raw data from their surveys. Botanist Glenn Rink's energy, experience, and agility were invaluable during springs surveys in remote environments; his participation assured completeness of data collection as well as safety of the crew. The surveys could not have been possible without the support of volunteers from Grand Canyon Wildlands Council, the University of Las Vegas, Grand Canyon Trust, and Northern Arizona University. I also appreciate the participation of Robert Jenkins of the Hopi Tribe, and Navaho Tribal Botanist Andrea Hazelton. ESRI donated software and training through their Conservation Grant Program, as well as through TechSoup.org. Doug Miller of Pennsylvania State University contributed guidance and new ideas, and participated on a springs survey trip in 2011.

Through the ECP Grants Program, as well as through TechSoup.org, ESRI has contributed software and training that have provided access to technology that otherwise would have been out of reach for our small organization. We greatly appreciate ESRI's generous support toward conservation organizations worldwide.