Springs Ecosystem Inventory Protocols

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Introduction

Springs Ecosystems

Springs are ecosystems where groundwater is exposed at, and typically flows from the Earth's surface (Fig. 1). Academically described as "groundwater-dependent surface-linked headwater wetland ecosystems," here we will just refer to them as springs. In our experience, spring sources are usually multiple; therefore we refer to these features in the plural form as "springs" or "springs ecosystems".

Fed by groundwater aquifers, springs occur in many settings, both underwater as well as in terrestrial environments. Springs vary greatly in flow, water chemistry, geomorphic form, ecological significance, and cultural and economic importance (Springer et al. 2008, Springer and Stevens 2009). Seeps are simply small springs, usually with immeasurably diffuse or small seepage.

While more obviously important in arid regions, springs are among the most productive and influential ecosystems in all landscapes. Springs serve as hydrogeologic windows into aquifers (Töth and Katz 2006, Kresic and Stevanovic 2010, Springer et al. 2014), critical water supplies, keystone ecosystems (Perla and Stevens 2008), evolutionarily persistent refugia for rare or unique species (e.g., Shepard 1993; Scarsbrook et al. 2007; Hershler et al. 2014, 2015), remarkable paleontological repositories, and socio-economical focal points of human culture and development (Stevens and Meretsky 2008, Gleick 2010, Scott 2014).

Fig. 1. Lockwood Spring, a limnocrene spring in Coconino National Forest, Northern Arizona.

Until recently, scientific research has been insufficient to understand springs form and function as socio-ecosystems, or to develop coherent, integrated inventory and data management protocols. Short-term springs studies and research projects have been conducted (reviewed in Danks and Williams 1995, Botosaneanu 1998, Stevens and Meretsky 2008), and hydrological studies of springs have focused on the delivery of groundwater to the surface (Springer and Stevens 2009, Hershey et al. 2010), but few studies have been conducted on springs as ecosystems. Only three springs complexes in the United States to our knowledge have been studied and monitored in sufficient detail to provide insight into ecosystem function and change over time: Silver Springs in Florida (Odum 1957, Munch et al. 2006); Montezuma Well in central Arizona (Blinn 2008); and Yellowstone National Park hot springs (Brock 1994). Additional springs ecosystem studies are underway, and improved understanding of springs ecosystem ecology will continue to influence inventory issues and techniques.

Threats to Springs

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

Impacts on aquifers and groundwater quality range from none to complete dewatering of the springs, resulting in substantial alteration of springs microhabitats, vegetation composition and cover, faunal occurrence and distribution, and increased abundance and role of invasive species (Fleishman et al. 2006, Unmack and Minckley 2008, Weissinger et al. 2012, Morrison et al. 2013). Removal of groundwater through pumping near springs sources reduces or eliminates surface expression of flow, jeopardizing ecosystem structure and function. In contrast to regional effects, some kinds of impacts are more common at specific springs types. For example, gravel mining is most common in stream-channel rheocrenic settings, while trenching, flow focus, and excavation are common practices at marsh-forming helocrene springs (e.g. Fig. 2). Both general and specific types of impacts are important because springs often serve as keystone ecosystems, and the loss of springs can reduce the ecological integrity of adjacent upland ecosystems. Because human use of North American springs extends over the past 15,000 years, springs stewardship planning should include consideration of human use as well as ecological sustainability.

Fig. 2. Heavily disturbed spring in Stanislaus National Forest, California.

Impacts at the sources of springs ecosystems commonly include partial or complete diversion and the construction of springs boxes. Flow capture prior to emergence is required by state and Environmental Protection Agency (EPA) policies to ensure that groundwater used for domestic purposes is not contaminated by exposure to the atmosphere. However, this practice eliminates the source area—the most biologically important habitat of the springs ecosystem. Instead of extracting all surface water, subsurface flow splitting can be used to ensure some flow continues to emerge at the source, while still providing unexposed groundwater for human consumption. Thus, springs management requires careful forethought: well-intended practices like fencing to exclude livestock may backfire as vigorous wetland vegetation growth can consume surface water habitat needed by aquatic biota (e.g., Kodrick-Brown and Brown 2007).

Despite the importance and threats to these resources, springs have yet to receive substantial attention or protection from water or natural resource managers or policy makers. Little attention has been paid to springs ecosystems in any major technical review or textbook on national water resources in the past two decades (i.e., National Research Council 1994, Mitsch and Gosselink 2000, Baker et al. 2004, H. John Heinz III Center 2008, Wilshire et al. 2008, Boon and Pringle 2009, Gleick et al. 2009, Solomon 2010, Waters of the U.S. 2016; but see Minckley and Deacon 1991, Stevens and Meretsky 2008, Kresic and Stevaovic 2010, Kraemer et al. 2014). This lack of scientific recognition is partially due to the inherently complex and multidisciplinary nature of springs ecosystem research, the lack of a lexicon with which to describe different types of springs (Springer et al. 2008, Springer and Stevens 2009), the generally small size of springs (falling within rather than among landscape analysis pixel sizes), jealous guarding of springs as domestic and agricultural water sources, and a lack of legislative protection (Glennon 2002, Nelson 2008).

Inventory

Inventory is a fundamental element of ecosystem stewardship, providing essential data on the distribution and status of resources, processes, values, and aquatic, wetland, riparian, and upland linkages (e.g., Karr 1991, 1999; Busch and Trexler 2002; Richter et al. 2003). Systematic inventory precedes assessment, planning, action implementation, and monitoring in a structured resource management strategy. Efficient, interdisciplinary inventory protocols also are essential for improving understanding of springs ecosystem ecology, distribution, status, and conservation. Here we introduce and justify efficient, effective inventory protocols for springs, and subsequently we describe assessment and information management protocols to improve springs stewardship across landscape management scales, from individual springs to springs distributed across large landscapes.

The U.S. Environmental Protection Agency, Army Corps of Engineers, many federal and state land and water resource management agencies, indigenous Tribes, various for-profit and non-profit non-governmental organizations, and many private individuals protect and manage ground and surface water quality, wetland and riparian ecosystem health, and other natural and social aquatic and wetland ecosystem functions (e.g., U.S. Fish and Wildlife Service 1979, 1980; National Research Council 1992, 1994; Brinson 1993; Davis and Simon 1995; Mageau et al. 1995; Society for Range Management 1995; Oakley et al. 2003; Sada and Pohlmann 2006; Stevens and Meretsky 2008; Kresic and Stevanovic 2010).

In the United States, springs inventory protocols should be consistent with federal land and resource management legislation (e.g., the Antiquities Act of 1906, the National Park Service Organic Act of 1916; the multiple use mandates of the U.S. National Forest Service and the Bureau of Land Management, the Clean Water Act of 1973, the Endangered Species Act of 1973, as amended). However, wetlands delineation and loss mitigation in the United States (U.S. Army Corps of Engineers 1987, Waters of the United States 2016) have consumed much technical and regulatory attention. Those federal wetland delineation concepts and techniques often are not applicable to springs, particularly naturally ephemeral springs, hot springs, hanging gardens, and other springs in bedrock-dominated landscapes. Development of springs inventory protocols for specific regions, individual states, or individual agencies may not be broadly applicable, and therefore may not contribute to the advancement of large-scale springs stewardship, or to improving springs ecosystem ecology (e.g., Stevens et al. 2006).

Efficient, interdisciplinary inventory protocols are needed that are applicable to all types of springs—subaerial or subaqueous, in any biome, and across watershed, state, and national-international boundaries. Such protocols will help advance the springs ecosystem ecology and stewardship, which are actively developing fields. Some, but by no means all, aquatic, wetland, and riparian monitoring approaches are appropriate or useful for springs inventory and monitoring. Development of inventory protocols for Mojave Desert springs administered by the U.S. National Park Service (Sada and Pohlmann 2006), and cold water New Zealand springs (Scarsbrook et al. 2007) have provided useful insights. Protocols for stream-riparian hydrogeomorphic inventory may be useful for surface flow-dominated streams and some rheocrene springs, but often are inappropriate for groundwater flow-dominated springs because of fundamental differences in the roles and impacts of surface geomorphological processes. For example, channel meander and bank configuration are shaped by surface-flow flooding, whereas springflow dominated channels often tend to be linear or erratic (Manga 1996, Griffiths et al. 2008). Also, beaver and large woody debris are widely regarded as essential to circumpolar stream-riparian functioning, but often play little or very different roles in springs ecosystems (Springer et al. 2014). Misapplication of stream-riparian and wetlands inventory techniques can distort interpretation of springs ecological integrity (Stevens et al. 2006).

Biological variables are often particularly important components of springs ecosystem management, and nearly all studies of springs to date have emphasized their biodiversity significance (e.g., Fig. 3). Despite the miniscule total area occupied by springs in the United States, we estimate that more than 10 percent of the nation's endangered animal species are springs-dependent taxa. Also, high concentrations of rare species occur at some springs, in aridland and mesic regions, as well as in submarine settings. Ecological risks to springs from groundwater pumping and source alteration are commonplace and numerous (Minckley and Deacon 1991, Stevens and Meretsky 2008). Regional, multi-springs inventories of biota include those for wetland plants (Patten et al. 2008, Spence 2008), Odonata (Stevens and Bailowitz 2009), aquatic Heteroptera (Stevens and Polhemus 2008), Coleoptera (Williams and Danks 1991), Trichoptera (e.g., Erman and Erman 1990, Erman 1992, Blinn and Ruiter 2009), and fish (Fagan et al. 2005) and other vertebrates. Such data provide a background for the scope of biotic resources that should be considered in springs inventory and monitoring.

Fig. 3. Sampling for rare invertebrates at a spring-fed pond near the north rim of Grand Canyon.

Springs as Socio-ecosystems

Widespread regard exists for springs as ecologically, socio-culturally, and spiritually important landforms (e.g., Nabhan 2008, Rea 2008, Phillips et al. 2009). Although much emphasis has been placed on hydrogeology and biological diversity, nowhere to our knowledge have regional inventories of indigenous cultural attributes of springs been systematically conducted. Neither have the ecological economics of springs been much explored. In one of the few analyses conducted in the U.S., Bonn and Bell (2002) examined recreation economics at four large springs in Florida from 1992-2002, reporting that an average of two million visitors per year contributed $60 million annually to those regional economies. Gleick (2010) reported that 80 million bottles of water were sold every day in the United States, many of which are labeled as "springs water", revealing the enormous economic value of springs. In addition, numerous springs contribute to the urban water supplies around the world (e.g., Petric 2010).

As scientists and practitioners, we recognize that many springs are under active anthropogenic management. The use of springs resources is necessary and appropriate for human well-being, and often is fully intentional. While such use is necessary and respected, we suggest that springs can be managed sustainably to support both ecosystem/landscape function, as well as goods and services for human steward(s). In general, if the aquifer is intact, springs ecosystems are remarkably resilient, and can function well ecologically while simultaneously providing goods and services. Because of their resiliency, springs often can be rehabilitated or restored to ecological sustainability with ease and at relatively minor expense.

We have seen successful examples of such stewardship, but far too often we have encountered springs that have been unnecessarily destroyed by poor management and neglect. Recent clarification of springs classification and ecosystem information needs (Stevens and Meretsky 2008, Springer and Stevens 2009) has set the stage for development of protocols to enhance systematic inventory and springs ecosystem research, and to improve stewardship. Our perspective is that we should work towards improving scientific understanding of springs ecosystem ecology, and springs that are used for human purposes should be sustainably managed for both societal and ecosystem functionality.

Inventory challenges often arise from an unfocused conceptual understanding of socio-ecosystem organization (Fig. 4). Components of a comprehensive springs

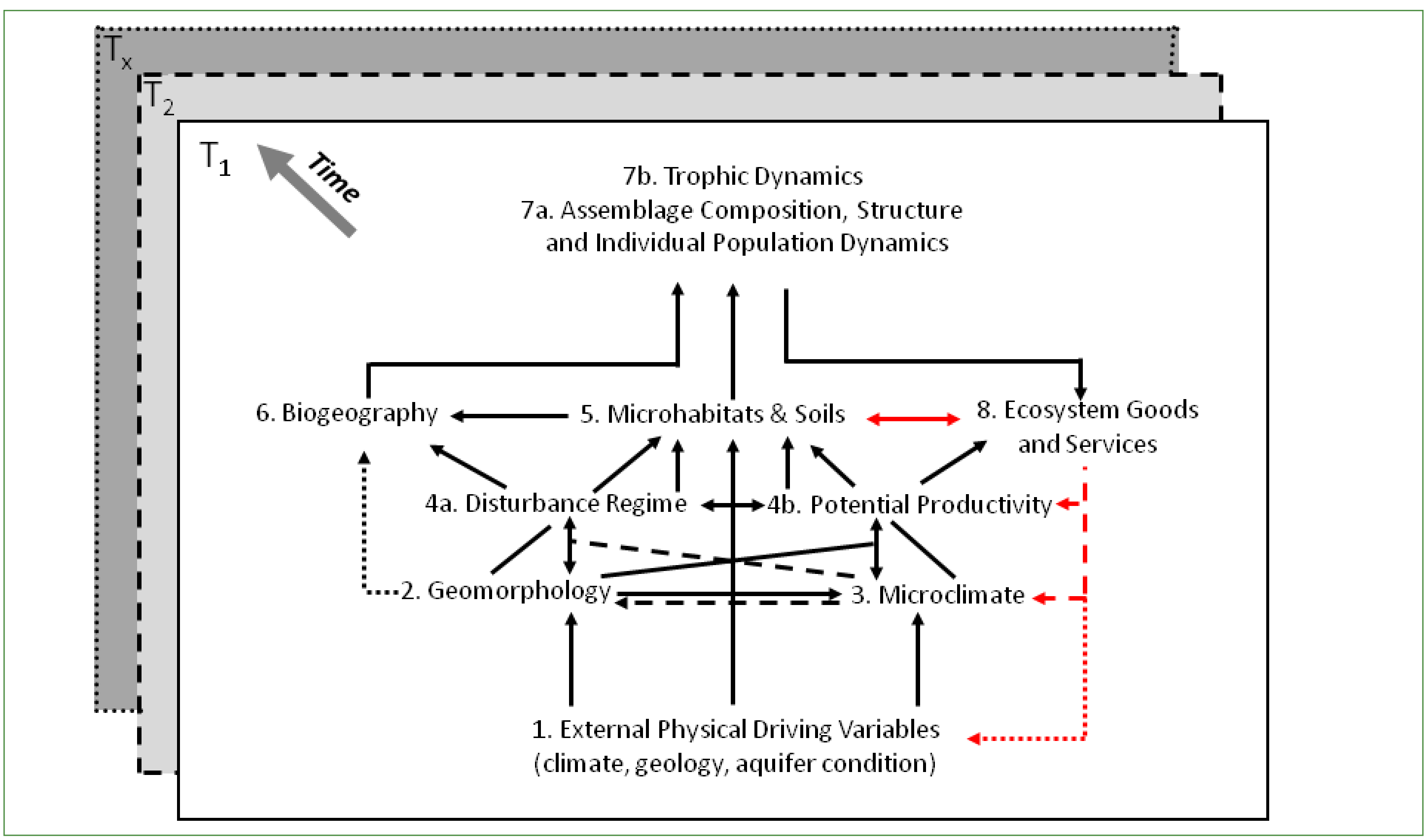


Fig. 4. Springs ecosystem conceptual model (modified from Stevens and Springer 2004). Dashed arrows reflect indirect influences, while red arrows indicate human impacts.

inventory follow from, and help refine the conceptual ecosystem model of Stevens and Springer (2004) and include: aquifer mechanics and sustainability (Tóth and Katz 2006, Kresic and Stevanovic 2010); flow and water quality (Meinzer 1923, Mundorff 1971, Springer et al. 2008, Trček and Zojer 2010, Kresic and Stevanovic 2010); aquatic and wetland vegetation (Patten et al. 2008, Springer et al. 2015); aquatic and wetland faunae (Williams and Danks 1991, Erman 1992, Hershler 1994, Ferrington 1995, Botosaneanu 1998, Hershler et al. 1999, Stevens and Bailowitz 2009, Hershler et al. 2014; e.g., Fig. 5); fish (Unmack and Minckley 2008); other vertebrates; cultural elements, including indigenous values and ecosystem goods and services (Nabhan 2008, Rea 2008, Phillips 2009); and the administrative context of springs stewardship, including regulatory issues (Stevens 2008). Relationships and feedback among the components and processes that shape springs ecosystems are often complex and contain the following attributes: multiple interacting physical processes, microhabitats that support different biotic assemblages, and the important socio-ecosystem roles played by springs. Most large springs have been used by humans since the Pleistocene, so managing springs for a pristine condition is ecologically inappropriate (e.g., Kodrick-Brown and Brown 2007). For springs ecosystem ecology to advance as a science, and to help improve stewardship, springs inventory data should be collected scientifically and organized to test and refine understanding of these complex relationships (Stevens 2008).

Fig. 5. Springsnails (*Pyrgulopsis sp.)* are often locally endemic to springs ecosystems. These specimens of a possibly new species were collected in the Spring Mountains National Recreation Area in Nevada.

Program Design

Springs stewardship is most effective when based on a scientific approach, including development of an effective administrative context; definition of clear, unambiguous goals and objectives; assembly of existing and needed information; development and implementation of a data management plan; comprehensive and systematic inventory; ecological assessment; prioritization of management needs and actions; conduct of management actions; monitoring as a scientific exercise with forethought, data collection, review of results, and feedback into future management actions. Consideration of contingencies and unexpected events also is essential.

If multiple stakeholders are involved in the management and decision-making on one or more springs, then scientific adaptive ecosystem management (AEM) should be employed (Christensen et al. 1996). AEM is the process of collaborative resource management to meet the needs of multiple stakeholders.

Here, we propose an integrated springs inventory protocol to provide rapid, reliable, and readily understood information on springs ecosystem components, processes, threats, and stewardship options. These inventory and monitoring protocols have been developed over the past 15 years from conversations with many natural resource specialists and managers, and have been tested on more than 1,000 springs of different types in different geomorphic and climate settings in North America.

We divide inventory into three levels, involving mapping, rapid assessment, and longer term management, research, or monitoring efforts. The protocols recommended here can be used at any landscape scale of inquiry, from that of a single springs ecosystem, to inventorying springs on a regional, continental, or global basis, and can be used for basic monitoring to quantify ecosystem changes over time.

We integrate selected existing methods into an efficient, integrated analysis at several levels of inventory intensity, which vary based on available time and funding. The inventory information compiled in SSI's Springs Online database is contributing to improved stewardship by federal, state, Tribal, and private springs stewards, as well as basic springs research. These contributions include groundwater basin definition, regional springs distribution and importance, and biodiversity patterns in relation to ecological gradients (Springer et al. 2015, Ledbetter et al. in press).

The inventory protocols inform a comprehensive springs ecosystem assessment protocol (SEAP), allowing springs stewards to quantitatively compare springs socio-ecosystem integrity within landscapes, determine stewardship priorities, and monitor and measure the effectiveness of management actions over time. The inventory protocols described here provide a quantitative foundation for understanding the physical, natural, cultural, and anthropogenic influences affecting springs ecosystem function and stewardship options.

Data and Information Management

Prior to beginning a springs stewardship project, it is important to compile, organize, and archive available data and plan for baseline and monitoring information management. The springs information management system and its metadata should be easy to access, secure to protect sensitive data, and readily allow for new analyses. Few such information management systems presently exist for springs ecosystem data. Often, the limited available information is disorganized and largely unavailable to land managers, researchers, and stewards.

SSI developed Springs Online—a secure, user-friendly, online database where users can easily enter, archive, and retrieve springs information (http://springsdata.org/; Fig. 6). This database is relational, providing the ability to contain many surveys related to each site and to analyze diverse variables and trends over time. It is broadly framed to accommodate a wide array of variables, schemas, and information types.

SSI developed Springs Online based on the assumption that springs steward(s) will want, use, and maintain a long-term information management program for their springs. In the case of large landscape manage-

Fig. 6. Springs Online at http://springsdata.org/ is a secure database designed to enter, analyze, and report on springs data. Users must create an account, and a sophisticated permissions structure protects proprietary or sensitive information.

ment units (e.g., National Parks, National Forests, and Tribal reservations), such an information management system needs to relate to the steward's goals as well as their geographic information system (GIS) program. Springs stewards are likely to need data archival, site photography, appropriate specimen curation capacity, and clearly-defined metadata and standardized reporting. Springs Online fills these information needs, providing a secure, user-friendly interface for data entry, and analysis. The fields in the database have dropdown boxes and are aligned with the field sheets to ease the data entry process. A typical Level 2 survey can be entered in less than two hours.

This technology is freely available to all springs stewards who sign up for an account. With interest, examination of the tutorial, or online or workshop training, virtually any English-speaking individual can use this electronic portal to compile, archive, monitor, and report on springs. Easy retrieval of information from the SSI database provides long-term evaluation of change and response to management activities. The user manual is available at http://springstewardshipinstitute.org/database-manual-1.

Information security is a high priority when archiving sensitive information gathered from Tribal lands, private property, and historical sites rich in artifacts in National Parks and Forests. Springs Online offers secure archival of such information and can assign permissions specific to a steward, land unit, or project.

Education and Outreach

Education and outreach are important to the success of large or expensive management projects. Outreach may extend from the lay public, to private landowners, to local, state, federal, and international agencies, and to NGOs, and can provide the transition from awareness to engaged action. Private land owners may have historical documents recounting not only the stories of their families' relationship to the springs, and sometimes information on flow, biota, and historic uses. Scanned documents and images can be uploaded and stored in the database, along with links to other sources of information such as video.

Volunteer citizen scientists may assist with springs inventory and ecological assessment, and thereby deepen their appreciation of springs. However, it is critical to provide the necessary training to protect the springs during inventory, to acquire accurate and useful data, and to assure that data are appropriately entered and archived for future reference.

Three Levels of Inventory

We developed the SSI springs ecosystem inventory as a rapid, comprehensive data collection process to be accomplished by a team of three to four experts with one or two assistants. While engaging students or volunteers as assistants is desirable, non-expert staff may increase observer bias and require additional supervision. Using expert team members assures scientific diligence and attention to detail (e.g., maintaining a calibration log for water quality equipment, understanding aquatic macroinvertebrate habitat relationships, and documenting specimen collections). Coordination among team members is necessary, and prior practice with data entry is needed to clarify organization and the sequence of field data collection.

We developed these protocols based on our experiences inventorying more than 1,000 springs, primarily in western North America, including the Great Basin, the Colorado Plateau (Springer et al. 2005), and southern Alberta (Springer et al. 2014), as well as in Florida, Pennsylvania, Wisconsin (USA), and Sonora (Mexico). These protocols embrace recommendations on springs inventory and monitoring made by Grand Canyon Wildlands Council (2002, 2004), the National Park Service, Sada and Pohlmann (2006), Otis Bay (2006), Springer et al. (2006, 2014), Stevens et al. (2006), Stevens (2008), the U.S. National Forest Service (2012), and individual researchers.

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

- Level 1 Inventory involves a rapid reconnaissance survey of springs within a landscape or land management unit, including brief (10-20 min./site) visits by 1-2 staff for the purpose of georeferencing, clarifying access, and determining sampling equipment needs (field forms in Appendix A).

- Level 2 Inventory is a detailed inventory of a springs ecosystem to describe baseline physical, biological, human impacts, and administrative context variables (field forms in Appendix B).

- ***Level 3 Inventory*** involves monitoring of springs selected for long-term studies, and includes variables measured in multiple Level 2 inventories, as well as other variables relevant to monitoring programs.

Springs inventory data gathered from in-office mapping and field site visits by a team of experts are compiled into the comprehensive, user-friendly Springs Online database.

Inventory techniques will continue to evolve as scientific understanding of this nascent field develops, as methods improve, and as these techniques are used to address specific and more sophisticated questions about springs ecology and stewardship. Further testing and refinement of these protocols are necessary and desired, particularly in boreal and subaqueous environments. Therefore, inventory protocol development is an ongoing process, and we welcome suggestions for improving them.

Background Information

Overview

Once the administrative context and focal questions of the program have been established, springs stewards should develop a synopsis of background information. This is important for those managing a single springs ecosystem for domestic water supplies as well as those managing large landscapes with hundreds or thousands of springs. Relevant background information includes: 1) regional groundwater hydrogeology and modeling of regional aquifers, including climate influences; 2) land use, research, and administrative history; 3) site protections; 4) regional ecology and biodiversity, particularly of sensitive species; 5) prehistoric and historic uses; 6) stakeholders issues; and 7) information management system design, including bibliographic information. This background information provides critical baseline and regional documentation on the landscape and societal context in which springs exist. Much of this information may already be available, but it should be compiled into concise, well-referenced, archived format, so that present and future stewards will have a clear understanding of the rationale and history of management decisions.

Regional Groundwater Hydrogeology

Knowledge of the hydrogeological status and responsiveness of regional aquifers is critical for understanding the condition and risks to the springs fed by those aquifers, and in relation to climate variability and change. Often such information is compiled and integrated in a groundwater model. Such models take into account regional geologic stratigraphy and structure, permeability of parent rock and recharge capacity, climate variability, residence time, well distribution and groundwater withdrawal history, and projected future withdrawal. Systematic compilation of springs distribution (as described in Level 1 inventory protocols below) is included in these groundwater modeling efforts. Prominent examples of modeling analyses of springs discharge in relation to regional aquifers include those for: Devils Hole, Nevada (Riggs and Deacon 2002); springs in Grand Canyon and the Verde River basin Arizona (Kreamer and Springer 2008); the Edwards aquifer (Mace and Angle 2004); and Silver Springs, Florida (Phelps 2004 , Scott et al. 2004). Such studies can help guide aquifer management policy, although such policies are often lacking or ineffectual in many US states.

Land Use and Administrative History

Clarification of policy issues and ownership is central to, and supersedes resource planning and stewardship. Governance policies and water rights should be compiled in an annotated format to clearly define resource management authorities and guide planning, implementation, and monitoring activities. Water rights for both surface water and groundwater, as well as property rights and ownership of springs and their adjacent lands should be clearly defined and documented prior to substantial management actions. Springs Online can link such documentation directly to the site for reference during assessment and planning.

A thorough understanding of previous scientific research is useful before engaging in fieldwork. Such an effort may reveal prior studies on groundwater modeling, rare species ecology, and land use history. The synthesis will illuminate background technological and conceptual issues and identify information gaps.

The inventory team should research site and rare species protection policies and priorities prior to conducting any field work. Archeological, cultural, site, or sensitive species issues (e.g. critical habitat designation of endangered species) may influence how, where, and when inventory data can be collected. The timing of site visits and sampling equipment may be prescribed by the U.S. Fish and Wildlife Service, state, Tribal , or private resource stewards.

Site Protection

Care should be taken when surveying springs ecosystems to minimize impact to the site. The springs ecosystems inventory team focuses their impacts on a relatively small area of springs sources, terraces, and runout stream channel banks. However, Cole (1992) determined that the degree of concentrated activity was the most important factor leading to localized anthropogenic impact. Other studies report that modest amounts of use can result in high levels of groundcover loss and soil exposure (Cole 1986, Leung and Marion 2000). Team members also should also exercise great caution when inventorying springs where federally listed, rare, or sensitive species of plants, invertebrates, or vertebrates have been reported or may be expected to occur.

Ensuring the integrity of the springs under study also is the responsibility of the inventory team: the site should be left in as close to its original condition as possible after the inventory has been completed. No propagules should be transported onto the site through nets or clothing. All aquatic sampling equipment, boots, and other materials that touch springs waters should be sanitized after each site visit to prevent the spread of chitrid fungi and other pathogens among springs and other water bodies. Protocols to prevent the spread of those pathogens include: spray-application of a >1% Clorox solution to aquatic equipment and boots; rinsing off the Clorox solution; and properly disposing the rinse solution. Spray-application of at least a 1% bleach solution to nets and other aquatic field equipment is recommended to sterilize field equipment. These sterilization solutions are themselves environmental contaminants that have deleterious impacts on amphibians and likely other springs-dependent species (e.g., Hangartner and Laurila 2012). Therefore, a follow-up rinsing with sterile water and containment of runoff is recommended. Placing the field equipment on a small plastic sheet can facilitate equipment sterilization and runoff containment.

Regional Ecology and Biodiversity

Understanding the ecology and biodiversity of the region is key to recognizing the importance of individual springs as refugia, and their role as keystone ecosystems (sensu Perla and Stevens 2008). Springs ecosystems often interact with the surrounding uplands, providing essential water, habitat, and food resources. In turn, springs are often strongly influenced by uplands biota and ecosystem conditions and processes, such as fire, logging, and development. Removal of large predators (e.g., bear, wolf, and large cats) influences native and non-native mammalian herbivore populations, resulting in overgrazing and vegetation composition changes at springs and riparian zones (e.g., Yellowstone National Park wolf-elk interactions, Ripple and Beschta 2011). Therefore, a description of the types and conditions of surrounding ecosystems is needed to develop understanding of such interactions and the ecological context of spring influence.

Sensitive species in a region often influence regional and local resource management decisions. Several groups of species play disproportionately important roles in management decision making, particularly endangered, extirpated, endemic, economically important, and exotic taxa. Springflow-dominated sites may serve as paleorefugia—long-term stable sites at which evolutionary processes can permit rare, relict or adapted endemic species to evolve or persist (Nekola 1999). Some types of springs, particularly stenothermal (thermally constant) limnocrenes, hanging gardens, and gushets (especially those in arid regions) serve as paleorefugia for numerous co-occurring endemic taxa (e.g., Montezuma Well, Blinn 2008; Ash Meadows springs, Deacon and Williams 1991; Cuatro Ciénegas, Hendrickson et al. 2008). Compilation of information on the changing status, distribution, and habitat needs of endemic and rare species is important background for springs inventory and assessment.

Prehistoric and Historic Uses

Springs are among the most important cultural sites in the landscape, supporting paleoarcheological remains and containing evidence of prehistoric and historic use, and harboring enormous contemporary cultural and economic values (e.g., Glennon 2002, Haynes 2008, Nabhan 2008, Rea 2008, Phillips et al. 2009; Fig. 7). An integrated, annotated history of human occupation and management of the springs and surrounding landscape helps identify springs that have significant sociocultural significance. In North America, most large springs have been intensively used by humans for the past 12,000 yr., requiring stewardship planning that includes human

Fig. 7. Springs often have a lengthy, but sometimes obscure history of use. Bennett Spring in Northern Arizona.

impacts (West and McGuire 2002, Kodrick-Brown and Brown 2007, Kodric-Brown et al. 2007).

Stakeholder Issues

The inventory team should compile and review a list of all stakeholders concerned with the landscape. Private landowners, non-governmental agencies, Tribes, researchers, and state and federal springs stewards may be familiar with springs locations and land use history. Consultation with those individuals will help identify management concerns that will focus monitoring and stewardship activities. Such an effort may reveal prior studies or other information on aquifer conditions, rare species ecology, and land use history. Compiling and understanding that information is required to plan logistics, and complete the administrative context of the ecosystem assessment. During the synthesis, the programs will establish dialogue with land managers or stakeholders regarding the status, value, management, and significance of their springs.

Field Work Planning

Site Selection

To be informative and useful to stewards, springs inventories in large landscapes must address stakeholder information needs and meet appropriate statistical sampling criteria. However, these criteria are not easily combined, except in situations in which most or all springs in a landscape are inventoried. Most stewards have questions about specific, high priority springs, and such springs are likely to be the largest and those with the highest potable water quality. Dozens or hundreds of other springs may exist in the land unit, about which the steward may only want general information until focal resources are discussed. Nonetheless, groundwater modeling will be improved by adding flow and geochemistry data from all springs in the landscape.

The inventory sampling strategy should be based on the steward's questions regarding the springs under their jurisdiction. If the study involves a large area, a Level I inventory of springs across the entire landscape is useful to understand the general distribution of springs. If the steward's primary questions are focused on what types of springs exist in the landscape, and the ecological integrity of those springs, the Level 1 distribution data can be used to randomly select a suite of springs for Level 2 inventories, with or without a stratified random sampling design. Springs often are spatially clustered, and springs within clusters are likely to be similar. A statistical cluster analysis can be conducted to identify groups of springs based on latitude, longitude and elevation. Clusters of springs can be randomly selected, and one or several springs can be randomly selected within clusters. It is advantageous to inventory a large suite of randomly selected springs to ensure sampling of rare springs types. Although the stewards may be interested in individual economically important springs, the rigor of the stratified random design should not be compromised by biased sampling.

Fig. 8. Volunteer coordination and training is essential to ensure credible scientific data and safety.

Stakeholder Involvement

Prior to conducting field work, the survey team should contact private landowners or the Federal, Tribal, state, county, or local entities involved with the springs to communicate goals and objectives about the project, acquire additional information, and to arrange access to springs included in the inventory. Because information collected on the sites is the intellectual property of the springs owner, the team needs to ensure the security and ownership of the inventory data with the steward.

Volunteer Coordination

Volunteers can provide an important work force for springs stewardship, but volunteer coordination and training is needed to ensure the credibility and proper entry of the data collected (Fig. 8). When working with state and federal agencies on land managed by these agencies, volunteer services agreement and release forms will need to be completed. A volunteer coordinator is often designated to perform the necessary recruitment, training, and logistical organization, and that individual should be intimately familiar with the project. Federal agencies typically have their own volunteer agreement forms.

When to Sample

In temperate regions with deciduous vegetation, springs base flow and water quality are most clearly interpretable during mid-winter, when transpiration losses are low. However, the middle of the temperate growing season is likely to be most revealing for biological variables. The timing of springs visits in tropical areas with seasonally varying precipitation is subject to similar arguments. While a single site visit is highly informative, Grand Canyon Wildlands Council (2004) reported that three site visits in different seasons were needed to detect >95 percent of plant species at large springs, and up to six site visits (including nocturnal sampling) were needed to detect most of the aquatic and wetland invertebrate taxa at large sites. Inventories for fish and amphibians likely require several visits, and detection of other wetland, riparian, and terrestrial vertebrates, such as avifauna and large mammals may require numerous visits through a long-term monitoring context. Assembling a reasonably complete vertebrate occurrence list at a given springs ecosystem is a long-term monitoring program element (Level 3 inventory).

Permits

Prior to field data collection, state, federal, Tribal research permits, or permission from private landowners, may be required, and separate permits may be required for each land unit visited if a project extends across political jurisdictions. Permitting requires advance planning and may substantially delay inventory, assessment, and rehabilitation work. If specimens are collected during inventory, appropriate repositories should be used or established, and voucher specimens should be collected, prepared, and stored in professional collections for further research, monitoring, or potential litigation

Crew Organization and Training

Level 2 inventory data are designed to be gathered during a 1-3 hr. site visit by 4-6 trained specialists and assistants, with the duration of the site visit primarily determined by the size and complexity of the springs. Level 2 staff should include a geographer, a hydrogeologist, a biologist with an assistant, and a socio-cultural expert. One crew member serves as the crew leader, and makes command-level decisions on logistics, safety, field equipment, and data management.

With proper planning and logistics coordination, Level 2 inventories should not exceed 3 hr. duration or $2,500 per site visit in 2016 U.S. dollars, including logistics, sample analyses, and data entry. Variation in cost depends on site remoteness and complexity of the site, as well as the level of detail desired for analyses. Additional time is needed for compilation of background information, logistics planning, laboratory analyses, specimen preparation and identification, completion of data management, and reporting for each site visited.

Coordination and training of the survey team should take place prior to the field season, including both laboratory and field activities. Workshops lead by SSI staff involve a combination of class time in the morning, followed by afternoon field sessions. Staff and trainees travel to local springs and perform a full Level 2 inventory. Data entry and database training also are available through the SSI website. Quality assurance of the data within the database depends on well-organized and thorough data-entry.

Logistics Planning

Following site selection, it is important to develop a schedule and route plan for the inventory team to access springs. The plan should minimize travel distance and time, and also indicates natural barriers that may delay or prevent access (e.g., river crossings, escarpments, etc.). For larger projects, it may be helpful to complete a route analysis in GIS. Note that road layers for remote areas often are inaccurate.

Crew Safety and Risks

Safety is first in importance for the field team, and while all team members need to be mindful, safety is a primary responsibility for the crew leader. Vehicular safety, communications, first aid, instruction in the use and care of equipment, field data management, and final decisions over the safety of access are concerns for each member of the crew and its crew leader. In remote areas, the crew should always carry sufficient supplies of water, food, flashlights, shovels, extra spare tires, and first aid and emergency supplies to deal with accidents and unexpected circumstances, such as rapid changes in weather. Hard hats and closed-toe boots are required in burned or construction areas. Georeferencing vehicles prior to starting on remote field inventories, will help ensure relocation of them, particularly at night, or if different return routes are taken.

Equipment List

The equipment useful for Level 2 inventories is listed in Table 1. This is by no means an exhaustive list, and the crew should develop and refine their own list, including backup and maintenance tools, parts, and materials specific to their project. It is nearly axiomatic that the more expensive a piece of field electronic equipment is, and the farther the crew is away from the vehicles, the greater the likelihood of equipment failure. Therefore, it is important to have back-up systems or a strategy to cope with equipment failure. The crew should establish a maintenance program that includes vehicles, first aid kits, and equipment maintenance that follows manufacturer guidelines.

The Level 1 inventory should inform the Level 2 team about field equipment needs and environmental conditions (e.g., steep slope, rough terrain, high magnitude springs flows, etc.) to reduce unnecessary transport of cumbersome or heavy equipment, such as a cutthroat flume. This will help keep the equipment load to a reasonable minimum.

Contingency Planning

Unanticipated Conditions

Contingency planning is an important part of field work. Weather conditions can challenge project success. Other unanticipated factors can include: landscape instability; fire-related area closure; threats from large animals; border or drug-related criminal issues; encounters with irate individuals; vehicular accidents; or the springs under study might be submerged by a beaver dam impoundment.

Encountering New Springs

Survey crews may encounter unmapped springs during the course of searches for reported springs. Prior to field work, the crew should plan for such discoveries. The choices range from simple georeferencing and photographing in a Level 1 site verification, to conducting a full Level 2 inventory of the newly discovered springs.

Inability to Locate Springs

Georeferencing coordinates commonly are inaccurate or blatantly incorrect (e.g., Fig. 9). The source of rheocrene springs can migrate up- or down-channel due to groundwater fluctuation. Such inaccuracies, particularly in rugged terrain or heavily forested areas may prevent the crew from finding the site. The crew should proceed to the designated point, establish a search radius, and designate a time limit for locating the springs (e.g. 250 m from the reported location and 20 min. search time). Communications are a high priority in such situations: each crew member should maintain a line-of-site or radio contact. Ultimately the crew leader will determine the search intensity, while ensuring the safety of the crew. When several poorly mapped springs are clustered, distinguishing one from another may be difficult or impossible.

Fig. 9. Example of inaccuracies and uncertainty with different data sources in North Kaibab Ranger District, Kaibab National Forest in Northern Arizona. Mourning Dove Spring is spelled differently in three databases, and is unnamed in two. Clustering of multiple sources in Mangum Canyon makes it difficult to identify individual springs.

Field Sheets

Field data sheets are the most efficient and reliable information documentation for Level 1 and 2 springs inventories. Multi-staff team information compilation and detection of data entry errors is impossible without hard copy field sheets, and springs-related data have proven too complex for on-site electronic data entry systems. Therefore, we recommend field data entry on hard copy sheets, with data entry in the laboratory soon afterwards and QA/QC.

The crew leader is responsible for keeping all field data from a site organized in a labeled folder or envelope and delivering it to the laboratory.

The SSI field sheets described below are designed to facilitate field data entry, and follow the organization of Springs Online database. Data fields are separated so that the crew leader can distribute pages to the appropriate team members (e.g., the botanist fills in the vegetation pages). Team members should sign their initials in the OBS field at the top of their pages to indicate who completed it the field work.

At the end of the inventory, the crew leader should collect all field sheets and fill out the page numbers at the top of each page (e.g., Page 1 of 8) and assure that the spring name has been included on every page. The section labeled as "Entered by," "Checked by," and "Date" at the bottom of the field sheet are to be completed in the lab when all data on that page have been entered into the database and checked by a supervisor.

Level 1 Inventory

A Level 1 inventory of the springs in a landscape is used to define the distribution, access, and springs types, as well as flow sampling equipment needed for Level 2 inventories. The Level 1 field sheet is found in Appendix A. Given the generally low-resolution understanding of springs distribution in North America and elsewhere (Stevens and Meretsky 2008, Ledbetter et al. 2014), we recommend that stewards of large landscapes (e.g., landscape parks, National Forest units, Tribal reservations) conduct a systematic Level 1 inventory of springs in their landscape prior to conducting a more intensive Level 2 inventory. In large landscapes, a Level 1 survey should be initiated by first reviewing available mapping data, and by conducting interviews with knowledgeable individuals about springs distribution. Such efforts, conducted prior to Level 1 inventory field work, will greatly reduce field search time and inventory costs.

Level 1 inventory field site visit protocols are described by Sada and Pohlmann (2006) and Stevens et al. (2006). A Level 1 springs site visit is a brief (10-20 minute) site visit for the purposes of georeferencing, photography, recording springs type, and determination of flow measurement equipment needs (Appendix A). Level 1 inventories are typically conducted by 1-2 trained individuals, such as technicians, scientists, or members of the educated lay public. This level of inventory is useful for identifying the distribution of springs in a landscape, and determining the need and methods for the more rigorous Level 2 inventory. The information gathered in a Level 1 survey should include: georeferencing (with equipment type, datum, and position accuracy), directions and caveats about access to the site; observer(s) and date; a verbal description of the springs; photographs of the source and microhabitat array; spring type and approximate springs-influenced land area; the methods best suited to measure flow (e.g., capture, weir plate, flume, or wading rod); and notes on biota. A Level 1 inventory can be performed during programmatic searches for springs or on an ad libitum basis as springs are encountered during other activities.

Level 2 Inventory

Introduction

A Level 2 springs inventory includes an array of measured, observed, or otherwise documented variables related to site and survey description, biota, flow, and the sociocultural-economic conditions of the springs at the time of the survey. To the greatest extent possible, measurements and estimates are to be made of actual, rather than potential, conditions—a practice needed to establish baseline conditions and for monitoring comparisons (e.g., Stevens et al. 2006). The protocols presented here were informed by discussion with many resource stewards and recommendations made by Grand Canyon Wildlands Council (2002, 2004), Sada and Pohlmann (2006), Springer et al. (2006), Stevens et al. (2006), Springer et al. (2008), Springer and Stevens (2009), and U.S. Forest Service (2012). These protocols are based on the springs ecosystem conceptual model of Stevens and Springer (2004) and Stevens (2008; Fig. 4). The variables selected are the suite needed to improve basic understanding of springs ecosystem ecology, as well as the site's ecological integrity and anthropogenic influences, including regional or local ground and surface water extraction or pollution, livestock or wildlife grazing use, recreational visitation, and climate change.

With appropriate background information, a single Level 2 site visit is sufficient for assessment of ecosystem integrity. However, the Level 2 inventory protocols and information management protocols presented here also are suitable for basic monitoring, and can provide baseline data for long-term Level 3 site management and restoration efforts. Level 2 springs inventories are rapid assessments of sites, and we regard activities such as wetland delineation, soil profile analyses, paleontological and historical use investigations, establishment of vegetation transects and plots, and other in-depth

Table 1. Recommended equipment list for Level 2 springs surveys.

Category	Field Equipment Used in Springs Inventory and Assessment
All	Background information: site location, description, geohydrology, and previous biotic surveys
All	Field datasheets, extra sheets, and 4 clipboards
All	Field computer (optional)
All	Pencils and permanent marker (Sharpie)
All	Personal safety gear; first aid kit, radios, flash lights
All	Protocols document
All	Screwdriver, pliers, and other tools to repair equipment
All	Spare batteries and parts for all equipment
All	Topographic maps of site at coarse- and fine-scale (1:24,000) resolution
All	Ziploc bags, Whirl-Pak bags (50 ea)
Biota-all	Field guides (plants, invertebrates, vertebrates, etc.)
Biota-all	Hand lens (10x)
Biota-aquatic	1% Clorox net sterilization in spray bottles, rinse water, and plastic sheet
Biota-aquatic	Inflatable boat, air pump, and paddles (deep water springs)
Biota-invertebrates	Dredge - Petite Ponar (deep water lentic sites only)
Biota-invertebrates	Ethyl acetate killing fluid (90%, 0.25L)
Biota-invertebrates	Ethyl alcohol (100%, 2 L)
Biota-invertebrates	Forceps (4 pr)
Biota-invertebrates	Glass vials 50
Biota-invertebrates	Hand lens 10X
Biota-invertebrates	Killing jar (3+)
Biota-invertebrates	Malaise Trap
Biota-invertebrates	Net - aerial sweepnet (2)
Biota-invertebrates	Net - hand (aquarium net (3)
Biota-invertebrates	Net – Kicknet
Biota-invertebrates	Net - Surber sampler
Biota-invertebrates	Paper or wax paper envelopes x 200
Biota-invertebrates	UV light trap
Biota-vertebrates	Binoculars 8x-10x
Flow	Baski portable cutthroat flume
Flow	Portable weirs - 45° and 90°
Flow	Velocity meter with wading rod and digital display unit, or FlowMaster
Flow	Volumetric containers, piping/tubing
Flow	Stopwatch with 0.01 sec timer
Geography	7.5’ Topographic map
Geography	Camera, batteries, digital cards (2)
Geography	Clinometer
Geography	Compass
Geography	Flagging

Geography	GPS unit (and spare as backup)
Geography	Graph paper for sketchmapping
Geography	Metric ruler (30 cm)
Geography	Munsell soil color chart
Geography	Pin flags
Geography	Solar Pathfinder
Geology	Hydrochloric acid (10% HCl) 100 mL bottle and dropper
Geology	Trowell, small or folding shovel
Geology	Sediment grainsize card
Geology	Stratigraphic column
Geography and Vegeta-tion	Cover density card
Geography and Vegeta-tion	Measuring tapes - 30 m and 50 m
Geography and Vegeta-tion	Plant press, blotter sheets, newspaper (several)
Geography and Vegeta-tion	Range finder (metric)
WQ	DI water (2 L/site)
WQ	Calibration log book for multi-parameter water-quality meter
WQ	Calibration solutions for pH, dissolved oxygen, conductivity, etc.
WQ	0.45 µm water filter and spare filters
WQ	Labeling tape
WQ	Latex gloves and mask
WQ	Multi-parameter field WQ meter; cables for temperature, pH, DO, SC, and optional (ORP, salinity, nitrate, ammonium, chloride, turbidity) probes; back-up meters; and WQ test strips
WQ	Nalgene bottles - 1 per site + 12 additional (250 mL, acid washed and deionized water rinsed; project dependent)
WQ	Nalgene bottles - 1 per site + 12 additional (10 mL, acid washed and deionized water rinsed; project dependent)
WQ	Syringes for filtering (several/site)
WQ	Thermometer (°C) for air and water

scientific and management activities as Level 3 research, management, and monitoring activities. Therefore, we do not recommend that such time-intensive efforts be included in the Level 2 rapid inventory protocol. Trend assessment also can be derived from Level 2 methods, but is considered a Level 3 activity because it is developed through monitoring.

In the following sections we describe the rationale behind selection of variables considered important for Level 2 springs inventory and the sampling methods. The text guides the reader through the 9-page Level 2 field form (http://docs.springstewardship.org/PDF/FieldForm.pdf; Appendix B). The level 2 inventory is designed with sufficient flexibility to add notes, observations, references, images, data files, and information on unique or unusual features of individual springs, as they are encountered. Table 2 provides the sequence of activities for a Level 2 survey. Table 3 lists the inventory variables.

Fieldsheet Page 1

Overview

A clear, concise description of the site and its microhabitats is essential for mapping, monitoring, establishing the source elevation (i.e., useful for groundwater modeling), and relating other basic physical elements of

Table 2. Sequence of activities for Level 2 springs inventory surveys. Sequence step 1 is to be performed first, then step 2, etc.

Sequence	Field Sheet Page(s)	Activity
1	---	Pick up and check gear, lock and GPS vehicle
2	---	Proceed to site
3	1,3	Record start time; Biologist searches/observes wildlife sign
4	9	Team walks site, checks for upstream sources, considers assessment variables
5	1	Team agrees on extent of springs habitat, and distribution and naming of microhabitats
6	---	Team establishes a base site for operations
7	1	Geographer begins georeferencing and sketchmapping the site (sketchmap includes springs name, date, N arrow, scale bar, locations of measurements, photography).
8	1,7	Water quality and Solar Pathfinder measurements are made at source
9	1	Site and measurement point photography
10	5-6	Botanist develops a plant species list
11	4	Biologist observes/collects terrestrial invertebrates
12	5-6	Botanist visually estimates % cover of each species in each microhabitat, and collects specimens of unknowns
13	8	Replicated flow measurement at point of maximum surface expression; after measuring flow, dismantle the equipment and restore the measurement site
14	4	Conduct quantitative macroinvertebrate sampling
15	9	Team collectively conducts assessment of hydrogeology, geomorphology, habitat, biota, and human impacts
16	---	Make sure all data have been compiled; recollect all field gear; leave the site untrammeled
17	---	Return to vehicle and proceed to next activity

the springs to its biota and human uses. The first page of the Level 2 inventory field form includes general geomorphic information about the site and the survey.

This first page should be filled out by the geographer, in consultation with the other staff members, and should include the observer's initials (OBS). Most of the variables on the first page are self-explanatory, and a list of options for some more technical fields is provided on page 2. Here we provide justification and commentary on those variables. The variables to be recorded are listed along the left margin of the sheet, and include General, Georeferencing, SPF, Survey, Microhabitats, and Images tabs.

General Section

Spring Name: Many springs are unnamed, and often the name on topographic maps conflicts with that used by the land managing agency or the NHD database. Typically it is best to use the name assigned by the land manager. In cases where no springs name exists, it is helpful if the inventory team gives the springs complex a distinctive, colloquial name—a creative name that honors the site. As many springs have multiple sources, using the plural form, such as "Sledgehammer Springs" is appropriate. To avoid confusion, avoid naming a springs ecosystem "Big", "Warm", "Cold", or "Rock" Springs. Similarly, avoid naming it by the dominant vegetation type (e.g., "Cottonwood", "Sycamore", or "Willow" Springs). Such names are overused and may be impermanent, in the latter case because vegetation may change through time. It is customary in the United States to forego the use of apostrophes in geographic names. Because most springs are not named and because the U.S. Geological Survey governs the naming of geologic features in the United States, the name applied by the inventory team eventually becomes the official name for that springs ecosystem. Therefore, it is important to assign a respectful name.

Springs Type: Effective stewardship requires understanding the status of the groundwater supply, and the type and context of the springs (Scarsbrook et al. 2007). Springer and Stevens (2009) identified 12 types of springs that include lentic (standing water; Fig. 10) and lotic (moving water; Fig. 11) springs. Non-flowing paleosprings are not included in that list.

Location and Ownership: Country, state, and county, land unit (e.g., US Forest Service, NPS, Private), and land unit detail (e.g., North Kaibab RD, Grand Canyon NP) are required fields in the database. The USGS quad and 8-digit HUC are optional, but are sometimes helpful. If left blank, these will be automatically updated in the database. Sites may be listed as sensitive by the steward due to their location (e.g., associated with archaeological resources), survey (e.g., hosting endangered species), both, or neither. Permissions in the Springs Online database can restrict access to that sensitive information, as the steward wishes.

Site Description: In this field, surveyors should describe the long-term context of the site. This includes the general geologic and geomorphic setting. Typically this description should apply to the permanent condition and features of the site. This is a free text field in the database, allowing plenty of room for describing the site, but not its condition (see below).

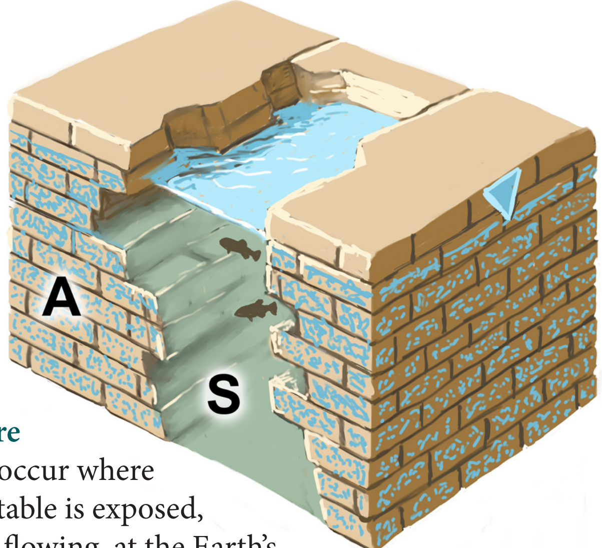
Georeferencing Section

Georef Source and Device: The device used (GPS, map, etc) indicates the quality of the location information. Keep in mind that steep canyons may result in a high GPS error (noted in EPE, below).

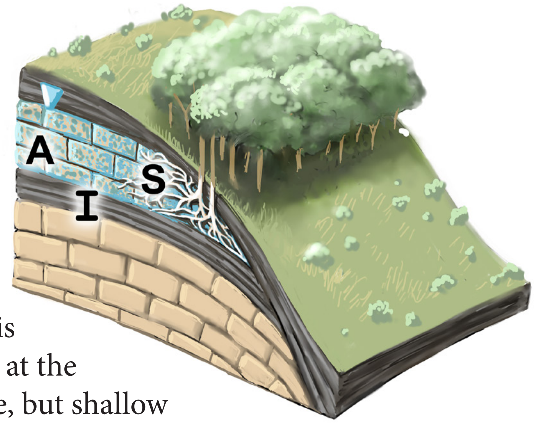
Datum: Generally surveyors should use NAD-83 or WGS-84, although when using a USGS Quad sheet, NAD-27 may be unavoidable. It is critical to document the datum used, as it may result in positioning error of up to 400 m.

Geographic Coordinates: Surveyors enter UTMs, decimal degrees, or both. However, the Springs Online database requires decimal degrees to add a new springs location. If using UTMs, be sure to include the zone. Declination is important for calculating true vs. magnetic north. Accurate elevation data are essential for groundwater modeling; however, accurate elevations are notoriously difficult to obtain using GPS. Therefore, using topographic maps or a digital elevation model may be more accurate than using GPS data for determining elevation. Generally, the geographer can have a higher confidence in the accuracy of GPS locations with a lower estimated position of error (EPE). Use the comment field for any concerns or notes about the coordinates (for example, if the source is under an overhang so the coordinates were taken 50 m away where a signal could be obtained).

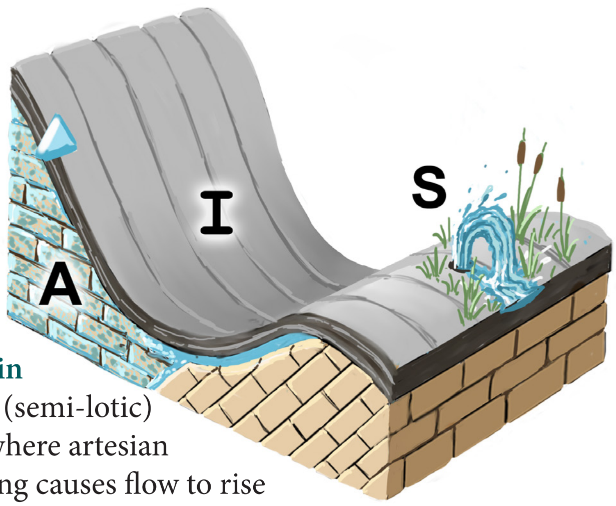
Access Directions: Completing this section can save future surveyors an enormous amount of time and limit danger. For example, if the site is only accessible from above, or it requires a difficult climb, this information is important to record. Further, if a site is only accessible with a long hike, or by crossing private land with large dogs, documenting these obstacles will expedite future inventory and monitoring efforts.



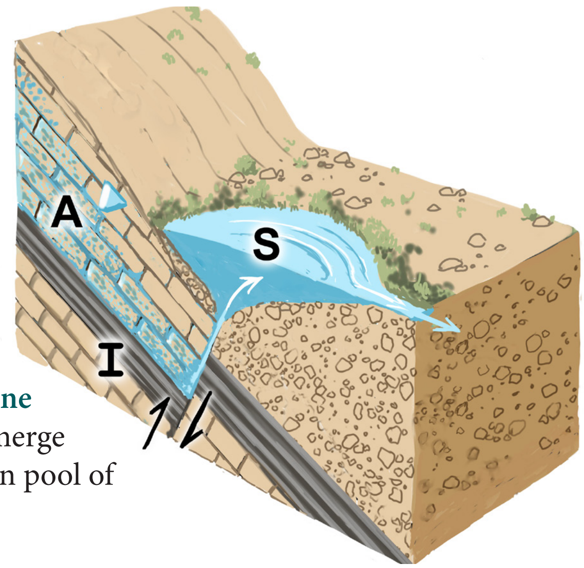
Exposure
springs occur where a water table is exposed, without flowing, at the Earth's surface.



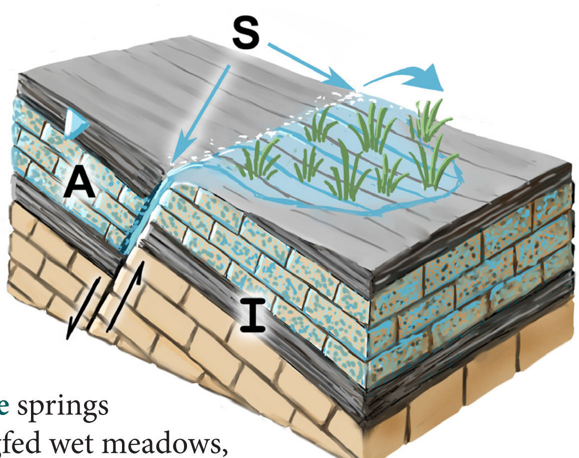
Hypocrene
springs occur where groundwater is not expressed at the Earth's surface, but shallow groundwater is discharged by transpiration through wetland vegetation.



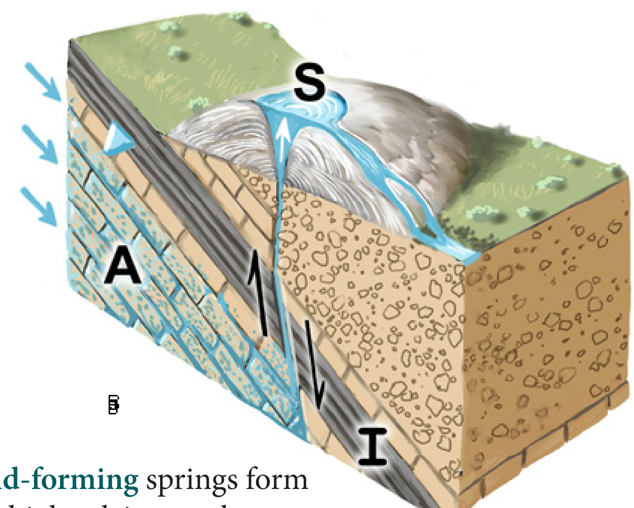
Fountain
springs (semi-lotic) occur where artesian upwelling causes flow to rise higher than the surrounding landscape.



Limnocrene
springs emerge into a open pool of water.

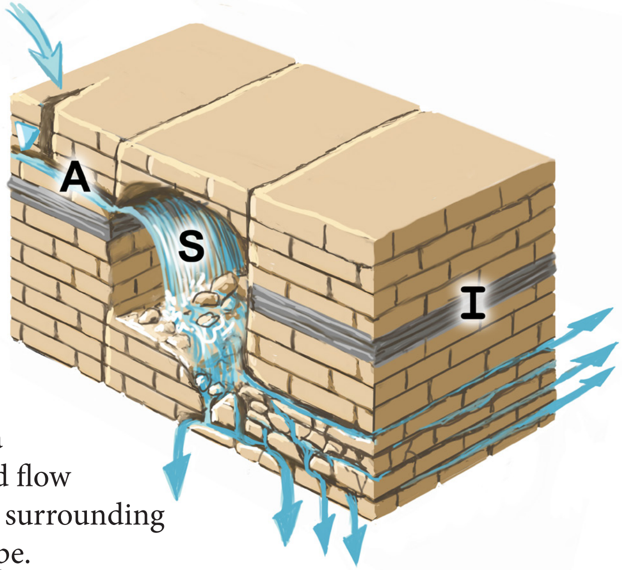


Helocrene springs are springfed wet meadows, called ciénegas at elevations up to about 2,135 m (7,000 ft), or groundwater-dependent fens at higher elevations.

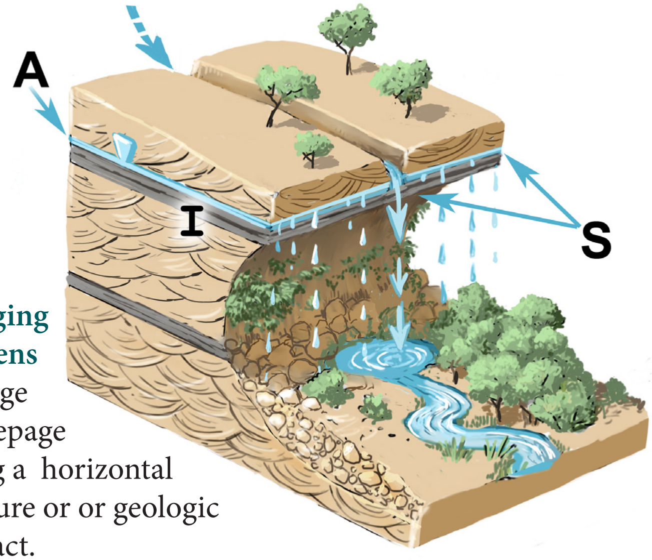


Mound-forming springs form where high calcium carbonate concentrations create travertine. This type also forms in the arctic where ice builds up, forming pingo ice hills or aufeis ice sheets.

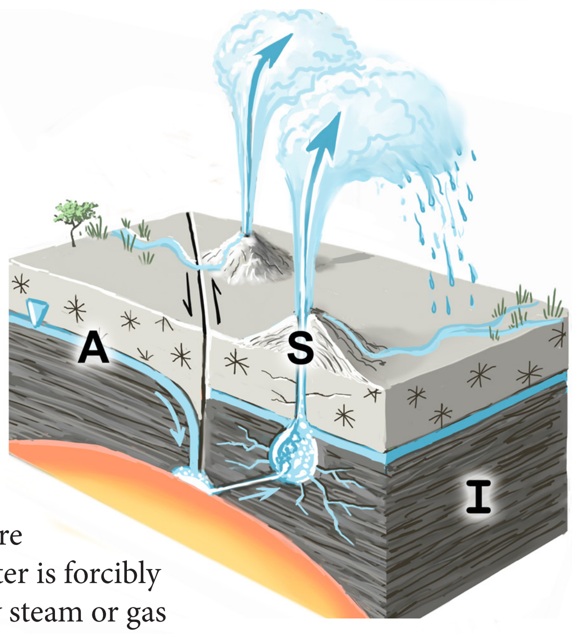
Fig. 10. Lentic and semi-lotic springs types, redrawn for SSI by V. Leshyk, modified from Springer and Stevens (2009).



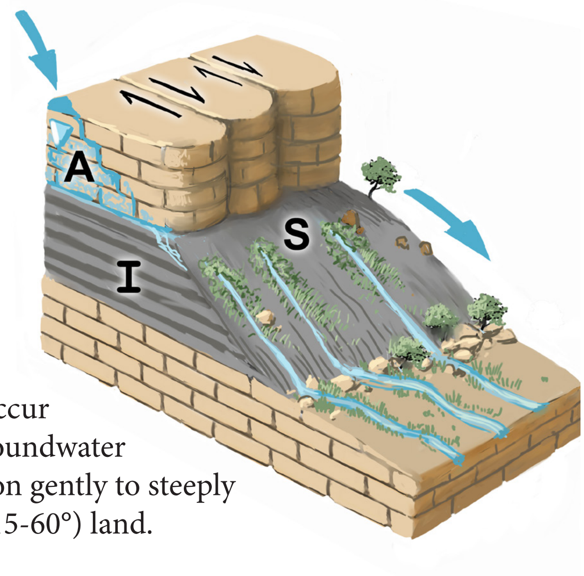
Cave springs emerge within a cave and flow into the surrounding landscape.



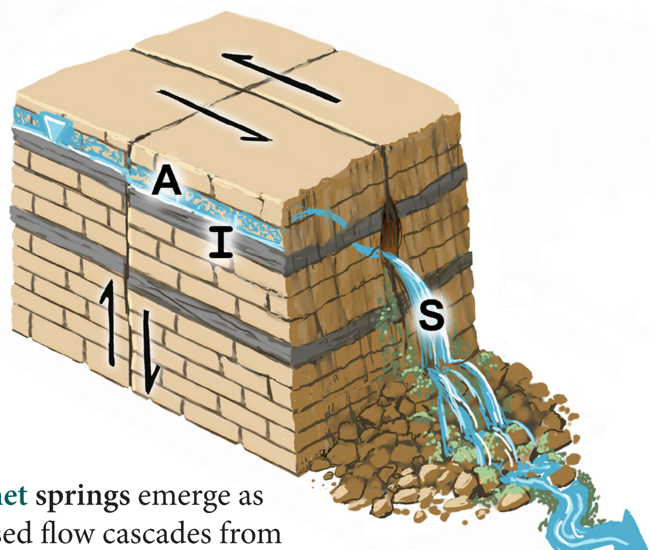
Hanging gardens emerge as seepage along a horizontal fracture or or geologic contact.



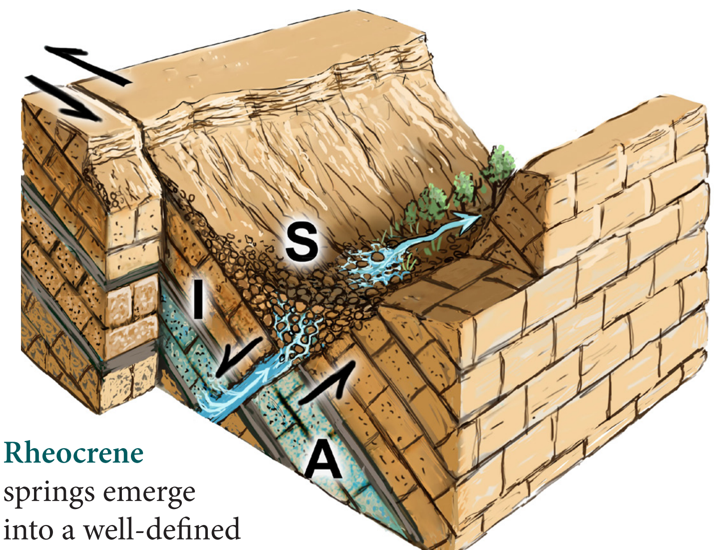
Geyser springs occur where groundwater is forcibly erupted by steam or gas pressure.



Hillslope springs occur where groundwater emerges on gently to steeply sloping (15-60°) land.



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



Rheocrene springs emerge into a well-defined wet or dry channel. They are commonly subject to regular surface-flow flooding.

Fig. 11. Lotic springs types, redrawn for SSI by V. Leshyk, modified from Springer and Stevens (2009).

Table 3. List and description of variables measured or observed during a Level 2 springs ecosystem inventory, and information sources: F – field site visit, L – laboratory analyses, O – office. See key of abbreviations and options in Level 2 field forms.

Variable Category	Variable(s)	Description	Data Source
General	Spring name, country, state/province, county/municipality, USGS Quad, 8-digit HUC, unique Site ID	General information about location of the site. A numeric Site ID is automatically generated when a spring is added to the Springs Online database.	O
Land Ownership	Land unit and detail	Steward (e.g., NPS, USFS, private) and land management unit (e.g., Grand Canyon National Park)	O
Site Description		Describe the permanent geomorphic context of landscape setting and springs type.	F
Access Directions	General location and access	Site access directions, being specific as possible, and noting any special precautions for returning teams.	F/O
Site Condition	Site condition	Describe site conditions as they present at the time of the inventory, including extent and forms of natural and human alteration of the site.	F
Georeference	Information source, datum, UTM zone, device, UTM easting, northing, latitude, longitude, elevation and accuracy (EPE, (m or ft), comments	Details of georeferencing	F
SPF	Solar radiation budget	Mean monthly sunrise and sunset time, measured using a Solar Pathfinder to calculate total % seasonal and annual solar flux; sum mean winter, spring, summer, autumn and total annual direct SF and percent.	F
Survey	Date, start time, end time, surveyor's full names	Who performed the inventory, when and for how long?	F
Project	Project name	Allows a set of surveys to be grouped and analyzed together.	O
Microhabitats	Describe geomorphically distinct microhabitats influenced by the spring	Identify each geomorphic microhabitat and its surface type and subtype; slope variability (low, medium, high); cardinal aspect (MN or TN); soil moisture, water depth and % cover; substrate composition by % surface particle size distribution and organic soil cover; % cover of precipitate, litter, and wood; average litter depth.	F
		Describe the size, unevenness, aspect, and surface covers of the microhabitats.	F
Images	Photographs	Describe photographs taken, indicate photo sites on the sketchmap, and include which camera was used. Make sure the photograph captures as much of the site as possible for rematching.	F

Sketch map	Site sketch map	Hand-drawn map, aerial photograph, or digitized map with scale, orientation, date, observers, landmarks, georeferencing points, photo points. Indicate the locations of flow measurement, photography, cardinal orientation, SPF and GPS measurements, and where the sketchmap is stored (attached, computer, etc).	F/O
Vegetation	Vegetation: Aquatic, wetland, and terrestrial plant species inventory	List all plant species detected, noting endemic and non-native taxa. Visually estimate % cover in each microhabitat by stratum: aquatic cover (AQ), non-vascular cover (NV), basal cover (BC; % woody stem area emerging from ground), ground cover (GC, graminoid/herb/non-woody deciduous), shrub cover (SC, 0-4 m woody perennial), mid-canopy cover (MC, 4-10 m woody perennial), tall canopy cover (TC, >10 m woody perennial). Very tall canopy (VTC) is optional.	F/L
Invertebrates	Aquatic, wetland, and terrestrial invertebrate species inventory	List the species detected, noting endemic and non-native taxa; quantitative timed area-specified kicknet or Surber sampling type, species enumeration, substrate, depth, velocity notes by microhabitat.	F/L
Vertebrates	Aquatic, wetland, and terrestrial vertebrate species inventory	List of species detected, noting endemic and non-native taxa.	F/L
Geomorphology	Emergence environment	Cave, subaqueous, subaerial, other.	F
	Flow forcing mechanism	Gravity, thermal, or gas pressure.	F
	Hydrostratigraphic unit: geologic layer of aquifer, rock type	Describe parent rock and rock type.	O,F
	Channel dynamics	Surface vs. springflow dominance.	F
	Source geology and flow subtype	Springs emergence: contact, fracture, seepage, tubular.	F
	Springs type(s); 1° sphere of discharge, 2°, 3° spheres of discharge	Describe the springs type and subtype(s), *sensu* Springer and Stevens (2009; See Appendix C).	F
Flow	Flow consistency	Describe perenniality of flow from long-term records, history, geologic features, dendrochronology, or the presence of aquatic organisms.	F/O
	Flow measurement technique(s), location, mean rate	Replicated flow measurement using techniques described; note the measurement location and on sketchmap.	F
Water Quality	Field WQ parameters: time of day; air and water temperature at source; pH; specific conductance (µS/cm); concentrations of dissolved oxygen, total alkalinity ($CaCO_3$, HCO_3)	Instruments must be calibrated for accuracy daily. Maintain a calibration log. Correct electrical conductivity for temperature to calculate specific conductance. Measure water chemistry as close to the source as possible.	F

	Laboratory WQ: Concentrations of base cations and anions, total dissolved solids, H and O stable isotopes (d^{18}OVSMOW and dDVSMOW), nutrients	Collect and filter water quality samples as close to the source as possible in acid washed container. Refrigerate, and analyze as soon as possible. Samples for nutrient analyses should be rushed to the analytical laboratory.	F/L
Cultural Resources	Archeological resources	Archeological surveys, literature review.	O,F
	Contemporary cultural resources (TCP, ethnobiology, etc.)	Interviews with Tribal elders, botanical inventory, site visits with Tribes, literature review	O,F
	Historical resources	Historical surveys, literature review, interviews with elders	O,F
	Human impacts and uses	Signs of human uses and impacts	O,F
Bibliography	List of citations	List of reports and other citations about the site	O
QA/QC	Data collection and data entry quality assurance/control	QA/QC efforts and analytical and information management methods, including such elements as random sampling of raw data, archival of calibration logs, etc.	O

SPF (Solar Pathfinder) Section

Photosynthetically active radiation (PAR) is important at springs in topographically complex terrains because it determines the amount of light available for springs vegetation, the duration and frequency of freezing and thawing in winter, and evaporation and relative humidity in the summer months. A Solar Pathfinder (SPF; Solar Pathfinder Inc. 2011; http://www.solarpathfinder.com/) can be used to quickly determine the mean monthly duration of direct insolation (Fig. 12). The SPF device consists of a reflective, transparent dome mounted on a template of the sun path diagram specific to the latitude of the site. The template estimates the mean percent of direct sunlight each half hour between sunrise and sunset each month, as defined by the horizon. The percent total potential solar energy for an average day during any month is calculated. With a 1-2 minute measurement, the geographer can determine the site's potential PAR for the entire year. Note that atmospheric limitation of solar radiation is not measured, and that cloud cover, dust, and humidity reduce actual PAR. The instrument can be calibrated against actual sunrise and sunset times when such opportunities exist. In general, the SPF is accurate to within 0.5 hours and approximately 5 m of the measurement point. In some settings, double sunrises or sunsets may occur.

Fig. 12. Solar Pathfinder is used to measure the photosynthetically active radiation at a springs ecosystem.

The Solar Pathfinder is by far the most efficient and least expensive approach to microsite collection of solar radiation data. Even 10 m digital terrain models cannot provide sufficiently precise information on microsite insolation. For Level 3 research, the SPF can be used to map solar energy budget around the perimeter of larger sites. Alternatively, a pyranometer and a weather station can be installed to monitor temperature, precipitation, and humidity in relation to solar radiation throughout the year.

Survey Section

Survey Date, Begin Time, and End Time: The survey date is a required field. The beginning and ending times are helpful for calculating the total time spent conducting the survey. The ending time is easily forgotten: all crew members should remind the crew leader to include this value at the end of the survey.

Surveyors: Enter full names of all of the surveyors. Although it is tempting to simply add initials, future staff will not necessarily recognize them.

Project: This is a required field in the Springs Online database. Projects are easy to add, and allow for easy data entry, QA/QC, and reporting.

Site Condition: This free text field should include specific circumstances at the springs at the time of the survey, including general ecological condition and conspicuous natural and anthropogenic features or impacts, such as recent flooding, grazing, recreational use, or fire. Such information is temporal, as opposed to the site description information (above).

Microhabitat Section

Springs are complex ecosystems, in part because they can include a suite of geomorphically distinctive microhabitats, which are patches that form through various physical processes (Table 4). The list of common microhabitats includes: caves, backwalls, (wet or dry), channels, pools, terraces, colluvial slopes, and anthropogenic features, the occurrence and relative size of which vary by springs and springs type. The team should discuss and agree upon the array of geomorphic microhabitats existing at the site prior to mapping and vegetation description (below). Microhabitat definition allows measurement of area and geomorphic diversity, plant species density, and other characteristics of the site. It is important to differentiate geomorphic microhabitats from vegetation, because vegetation cover may extend across portions or several entire microhabitats. Soil moisture, texture, and composition, as well as observations on soil quality and the extent of disturbance (e.g., trampling by livestock) are recorded for each microhabitat (Schoeneberger 2002).

Microhabitat Description: Some sites will only contain one or two microhabitats, while large, complex sites may contain many. Microhabitats are listed from A-G (or more if necessary) on the field sheet. The survey crew should assign a unique letter name to each that all can easily remember. For example, there could be a wet channel (A), dry channel (B), west terrace (C), and east terrace (D). Be conservative in all estimations.

Area: The crew member responsible for developing the sketchmap should calculate the area of each microhabitat in square meters. For smaller sites, surveyors should lay out a metric tape along the long axis of the springs ecosystem (Fig. 13). For very large sites, surveyors can use a rangefinder or GPS device to walk the perimeter.

Surface Type and Subtype: Microhabitat type values are listed in Table 4. Surface subtypes include: channel (CH) riffles, runs, margins, and *Eph*(emeral); wet or dry colluvial slope (CS) or sloping bedrock (SB) surfaces; channel terrace (TE) in the hydro- (H; flooded >annually), lower (L – flooded every 1-2 yr), middle (M; flooded every 2-10 yr) or upper (U; flooded >10 yr) riparian zone (RZ; e.g., "MRZURZ"). All surface types can have an anthropogenic subtype (All).

Slope Variability: This is judged as low, medium or high based on the consistency of the slope in a microhabitat. For example, a vertical wall would be given a low slope variability value if the entire surface is consistently 90°.

Fig. 13. The survey crew should stretch a metric tape along the long axis of the site, and perpendicularly.

Table 4. Matrix of springs types and likely associated microhabitats. Black – high likely occurrence of that microhabitat at that springs type, gray – moderate likelihood of occurrence, blank – low likelihood of occurrence.

	Microhabitat Type													
Springs Type	Backwall	Cave	Channel	Colluvial Slope	High-gradient Fen Ciénega, Marsh	Low-gradient Fen, Ciénega, Marsh	Madicolous	Lentic Shoreline	Pool	Sloping Bedrock	Spray Zone	Spring Mound	Terrace	Other
Cave	Black	Black	Black				Gray		Gray	Black			Gray	Gray
Exposure		Gray		Gray				Gray	Black	Black				
Fountain			Gray		Gray	Gray			Gray		Gray		Gray	Gray
Geyser		Gray	Gray				Gray			Gray	Black	Black	Gray	Gray
Gushet	Gray	Gray	Black	Black	Gray	Gray	Black	Gray	Gray	Black	Gray		Gray	Gray
Hanging Garden	Black	Gray	Black	Black	Gray	Gray		Gray	Black	Black			Black	Gray
Helocrene			Gray	Gray	Gray	Black		Gray	Gray				Gray	Gray
Hillslope	Gray		Gray	Black	Black	Gray	Gray			Gray			Gray	Gray
Hypocrene			Gray	Gray	Gray	Gray				Gray		Gray	Gray	Gray
Limnocrene			Gray			Gray		Black	Black	Gray			Gray	Gray
Mound-form	Gray		Gray	Gray		Gray		Black	Black	Black		Black	Gray	Gray
Rheocrene			Black	Gray				Gray	Gray	Gray			Black	Gray

Aspect: Record the cardinal orientation of each microhabitat, as measured with a Brunton or a sighting compass, and note whether the compass has been adjusted for declination (i.e., magnetic versus true north). Recall that $360^{\circ} = 0^{\circ}$. If magnetic north is used, enter the declination value, recalling that declination also affects the setup of the Solar Pathfinder. The Springs Online database converts magnetic to true north.

Slope Degrees: Measure slope angle of each microhabitat patch in degrees using a clinometer.

Soil moisture: Moisture is visually estimated as the springs-generated moisture in surface soils on a 0-10 scale, ranging from: dry (0 = no soil moisture, soil easily separates), moist (3 = little moisture), damp (moderate moisture), wet (6 = soil easily sticks together), saturated (8 = completely wet, added water does not soak up, but no standing water), and inundated (10 = water flowing through or over the surface). These categories are also listed under #6 on Page 2 of the field sheets.

Water Depth: Measure the maximum depth of water in cm within each microhabitat.

Water %: Percent wet is visually estimated as the percent of the microhabitat surface that contains open water.

Substrate %: The visually estimated percent cover of substrate grainsizes is recorded on the datasheet under each numeric category. These soil texture categories follow a modified Udden (1914)-Wentworth (1922) scale: 1) clay, 2) silt, 3) sand (0.1-1 mm), 4) pea gravel (1-10 mm). 5) coarse gravel (1-10 cm), 6) small boulders (10-100 cm), 7) large boulders (>1 m), 8) bedrock, and 9) organic soil, including peat. Soil color (measured with a Munsell color chart) can indicate of various soil types and is used in Level 3 survey activities, such as wetland delineation.

Prec(ipitate) %: Percent cover of precipitate is visually estimated across the entire microhabitat. In some cases, precipitate may cover litter and wood and can therefore be as high as 100%.

Litter %: Percent litter cover on the mineral soil (Schoenberger et al. 2002) includes the percent of leaves, twigs, and small downed branches (<1 cm diameter) covering the ground, and should be visually estimated in each microhabitat.

Wood %: Percent cover of branches or logs >1 cm in diameter is visually estimated, with the proviso that percent litter cover and percent wood cover cannot exceed 100%.

Litter (Depth; cm): Three or more measurements of litter depth should be averaged from different areas in the microhabitat and to estimate litter depth across the entire microhabitat.

Images Section

Surveyors should take site photographs that capture, to the extent possible, the context and condition of the springs ecosystem under study. Such photographs also can be used for long-term monitoring comparisons. However, heavy vegetation cover can obscure important site features, so selection of photo points should be carefully considered. Surveyors should take images of other features and biota (e.g., singly-occurring plant species that should not be collected). These can be uploaded into the plant, vertebrate, or invertebrate data forms in Springs Online. Typically only 1-3 site photographs are uploaded into the Springs Online database, and additional images should be labeled and stored for future reference.

Camera Used: In this field, surveyors should identify whose camera was used to take photographs of the site and where those site photographs are stored. Photographs are commonly misplaced or lost during and after inventory projects.

Photo # and Description: Surveyors should document photo numbers generated by the camera and describe the subject of the photograph. Cameras with GPS capability can help to identify the location of photographs, but this does not identify the subject matter.

Sketch Map Location: This refers to the location where the sketch map is stored (e.g., in a field book, in a folder, or electronically in a database).

Sketchmap

Once the microhabitats have been identified, the geographer should field map them on an ortho-rectified site photograph, field tablet, on graph paper, measuring the dimensions and cardinal orientation of the microhabitats (e.g., Figs. 14 and 15). The length and width of the site should be measured with a metric tape or rangefinder. Once the site is outlined, the sketch map should include distinct features, such as: 1) site name, surveyors, date, a scale bar; 2) a sketch of the site to approximate scale, flow direction, springs source(s), the configuration of associated channels, pools, terraces,

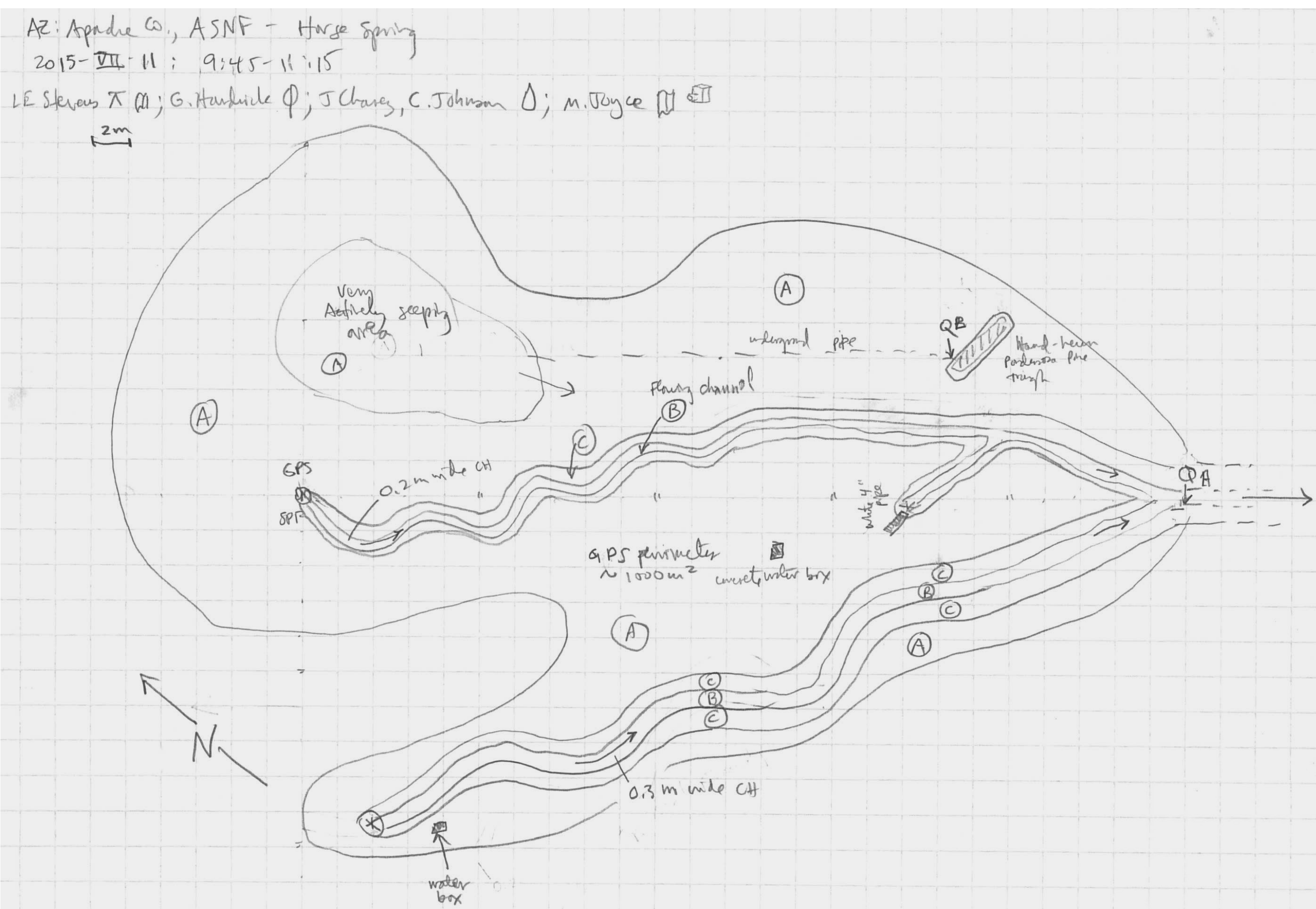


Fig. 14. Example of a field sketchmap. Horse Spring on Apache-Sitgreaves National Forest, Arizona.

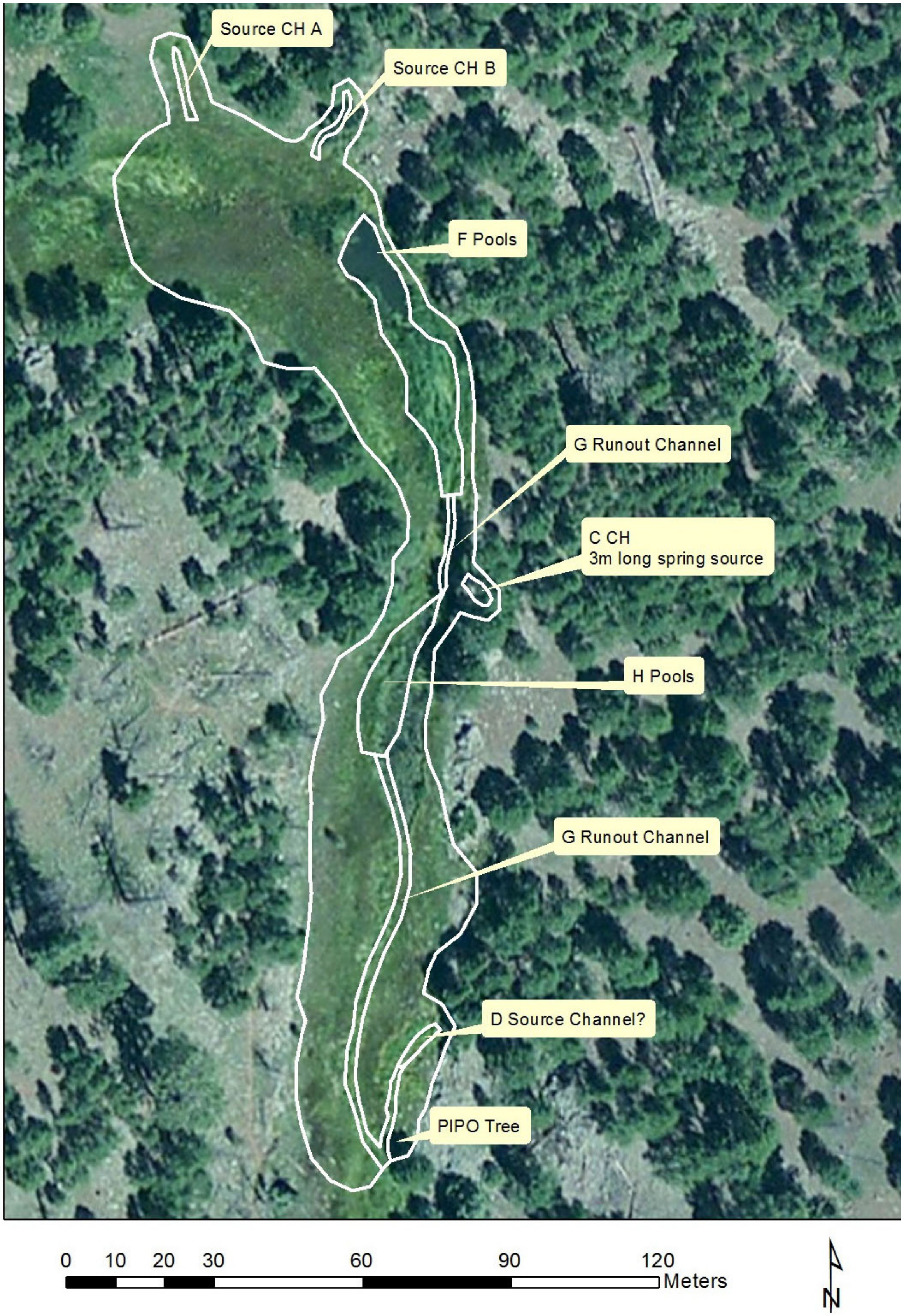


Fig. 15. Example of a sketchmap generated by walking the perimeters of microhabitats using a GPS, then bringing the data into ArcMap, refining the polygons, and adding labels. This method can be much more efficient and accurate for large, open , flat sites. It also is sometimes possible to draw polygons using aerial imagery. Either method is not feasible at small sites, or at those with dense vegetation or steep terrain. The site shown here is from LO Spring, Kaibab National Forest, Arizona. Aerial imagery courtesy of ESRI.

and other landforms indicated; 3) points at which georeferencing, photography, and Solar Pathfinder measurements were taken; and 4) roads, trails, spring boxes, pipes, troughs, and other constructed features. Be sure to collaborate with the entire team to assure that the sketchmap matches the microhabitat descriptions and the vegetation cover.

The sketchmap is scanned and uploaded into the survey at Springs Online, and included along with site photographs in the archives.

Fieldsheet Page 2

This page contains lists of options for many of the variables found on the first page. For example, options for #1 Discharge Sphere (Spring Type) at the top of page 1 include: anthropogenic, cave, exposure, fountain, geyser, hanging garden, helocrene, hillslope, hypocrene, limnocrene, mound-form, and rheocrene springs types (Figs. 10 and 11). This system uses less space than listing all of the options on each field form. As surveyors become more familiar with the options, they will need to refer to this list less often.

Fieldsheet Pages 3 and 4

Fauna overview

All aquatic and terrestrial macrofauna detected at the site should be documented. We recommend that the biologist spend at least five minutes at the site prior to the arrival or disturbance by the other team members to observe wildlife or sign that may subsequently disperse or be obliterated (Fig. 16). Aquatic and terrestrial macroinvertebrate detection methods differ considerably and are described separately below.

Aquatic and wetland life at springs commonly includes: Mollusca, Hexapoda, other invertebrates; fish; amphibians and reptile taxa; and birds and mammals. Species groups that are prone to endemism at aridland springs in the USA include: hydrobiid springsnails (Sada and Pohlmann 2006, Hershler et al. 2014); flatworms; physid aquatic snails; aquatic amphipods and isopods (Blinn 2008); various families of stoneflies; several families of Heteroptera waterbugs (especially Nepomorpha; e.g., Stevens and Polhemus 2008); dytiscid and dryopoid beetles; cyprinid minnows and cyprinodontid pupfish; cyprinid and cyprinodontid minnows (Nelson 2006); other fish; and amphibians (e.g., http://www.pwrc.usgs.gov/naamp/index.cfm). In addition, rare but non-endemic taxa, as well as species potentially new to science may be detected during springs surveys (Sada and Hershler 2002, Sada and Polhmann 2003, Stevens and Meretsky 2008, Stevens and Polhemus 2008, Stevens and Bailowitz 2009). Techniques for sampling vary by taxon, requiring specific equipment, preservation protocols, and considerable field and laboratory expertise.

Terrestrial Vertebrates

Documenting the use of the springs by terrestrial fauna is important for understanding the ecological role of the springs to the surrounding ecosystem. A wide array of terrestrial vertebrate taxa may occur at springs, including: fish, amphibians, reptiles, wetland birds, and mammals. Wildlife use of springs can be surprisingly intensive. For example, Grand Canyon Wildlands Council, Inc. (2002) reported 35 bird species, some in great abundance, watering at a small, remote spring on the North Rim of Grand Canyon during a Level 2 site visit. Grand Canyon Wildlands Council, Inc. (2002, 2004) reported two- to five-fold higher avian (and butterfly) density and species richness at springs as compared to the surrounding uplands. Although many terrestrial vertebrate species may be detected during a single site visit, developing a relatively complete list of the species present will require many visits at different times of the year, a Level 3 inventory effort. While all wildlife observations should be noted, quantification of terrestrial invertebrates and vertebrates cannot be completed during a Level 2 rapid assessment.

Fish in springs are most effectively sampled through Level 3 monitoring. However, the presence of fish should be noted in Level 1 and Level 2 surveys to alert future observers of needed equipment. During Level

Fig. 16. Often surveyors will only find signs of vertebrate species, such as still-warm bear scat. This can be noted on the vertebrates sheet under species name, with detection type as "sign" and "scat" under comments. The image can also be uploaded into the Springs Online database.

2, surveys identification and visual assessment of fish numbers are recorded. If permitted, specimens can be netted and, if necessary, preserved for identification. Recommendations in a Level 2 inventory about Level 3 monitoring should be made, including the habitats to be sampled, specific questions to be answered, and methods to be used, including: underwater methods (scuba diving and snorkeling), passive capture (hoop nets, Trammel nets, gill nets, minnow traps and weirs), active capture methods (seines, trawls and dredging), or backpack or boat electrofishing. Zale et al. (2013) provides details on the above mentioned techniques, as well as specimen handling, data management, design and, analysis.

Herpetofaunal detection and monitoring should generally conform to the data standards and protocols of the U.S. Geological Survey (reviewed in Dodd 2007), the U.S. Army Corps of Engineers (Guilfoyle 2010), and the National Forest Service multiple species inventory and monitoring protocols (**http://www.fs.fed.us/psw/programs/snrc/featured_topics/msim/documents/msim_chapter_8_terrherps_fnl.pdf**). If surveyors are able to take identifiable images of the species observed, they can be uploaded into the Springs Online database (e.g., Fig. 17).

Avian detection will vary hourly and seasonally (Manley et al. 2006). Bird observations will be opportunistic during Level 2 inventories, but Level 3 methods can employ modified point counts or visual encounter surveys, with detection types including sight, sound, or sign (e.g., feathers, scat, tracks). Observations of species or sign within 100 m of the springs ecosystems should be associated with the site survey. Species observed greater than 100 m from springs ecosystems are more difficult to confidently associate with the site and therefore can be noted on the data sheet, but not be included in the site list. Level 3 point count methods are described in the National Forest Service multiple species inventory and monitoring protocols (**http://www.fs.fed.us/psw/programs/snrc/featured_topics/msim/documents/msim_chapter_3_landbirds_fnl.pdf**).

Fig. 17. A black-tailed rattlesnake (*Crotalus molossus*) basking in the outflow from a warm spring along the Rio Grande river below Big Bend National Park.

Mammal detection will similarly be opportunistic during Level 2 inventories. Level 3 detection and monitoring uses visual encounter surveys. Such methods target diverse taxonomic groups and are less expensive than other live trapping or photographic methods. Observations of mammalian species and their sign within 100 m of the springs ecosystem can be associated with the site survey, and detection types include sight, sound, or sign (e.g., scat, tracks, kills, rubs and scent markings, etc.). Level 3 motion-activated photography, track plates, and hair snares may be used for more in-depth research.

Aquatic Macroinvertebrates

Many riparian and aquatic invertebrate taxa can be documented with the first Level 2 site visit. However, Grand Canyon Wildlands Council (2004) reported that several seasonal site visits in different seasons and years were needed to detect 90 percent of the macroinvertebrate taxa present. For aquatic invertebrates, we recommend intensive spot sampling to detect as many of the species present as possible. Care should be taken to document species in various microhabitats, including: riparian and aquatic vegetation; along shoreline; and in madicolous, pool surface, water column, benthic, and hyporheic zones.

If sufficient flow exists (flows with >2 cm depth across areas exceeding 10 cm width), timed quantitative benthic sampling also is appropriate to establish baseline density (number of individuals per m^2/min of sampling) and species density (number of species per sample or per m^2). Quantitative benthic sampling techniques involve timed, replicated, and area-specific kicknet, Surber, Hess basket (mesh sizes of <1 mm), or petite Ponar dredge sampling, as described by Merritt et al. (2008) and the Environmental Protection Agency (**http://www.epa.gov/owow/monitoring**). At least three quantitative samples should be collected, and in Level 3 monitoring, sampling should be conducted until variance in species richness and abundance stabilizes. Malaise, pitfall, colored pan, and ultra-violet light trapping, as well as drift and emergence trap sampling also are informative, but are Level 3 efforts.

Sampling for crayfish or other invasive invertebrates involves spot sampling, quantitative D-netting or seining, depending on project information needs and time available, with catch per unit effort (CPUE) or area as a standard metric. Great care must be exercised if protected species are present, and specific instructions about sampling for or around such species should be reviewed by the U.S. Fish and Wildlife Service and specified on the research permit. Stream invertebrate and vertebrate sampling is performed in an upstream direction, to limit error related to drift into sampling nets.

Visually estimated percent cover (VE%C) of aquatic substrata and other aquatic habitat variables are recorded at each benthic sampling site. As with soils documentation, benthic grainsize is visually estimated using the modified Udden (1914)-Wentworth (1922) scale. Velocity, depth, algal or vascular plant species and cover, and water quality variables also should be recorded for each quantitative sampling site. Springs often support limited habitat and substrate; therefore, not all of the categories mentioned above may be present.

The appropriate quantitative method(s) to collect aquatic macroinvertebrates should be selected for each specific habitat type. The following sampling methods are commonly employed in aquatic invertebrate sampling.

Kick-Net: The kick-net sampling technique is a quantitative method that is used in flowing water in depths >2 cm. The kick-net is held on the stream floor perpendicular to the current, setting the pole ends firmly into the sediment to stabilize. For shallow streams, a 0.09 m x 0.09 m frame can be placed on the stream floor and vigorously disturbed with a trowel or probe for one minute. Gravel and cobble substrates should be rotated and scraped on all sides while being disturbed to displace macroinvertebrates into the net. For water depths greater than 0.5 m, use a kick-net with an area of 1 m^2, and for water depths 0.1 - 0.5 m use a D- or dip net and sample a smaller area (often 0.09 m^2) because flow may not be sufficient to deliver specimens to the net.

Fig. 18. Surveyors collected a predaceous diving beetle larvae attempting to feast on a grasshopper. Both were documented and released at a spring in Apache-Sitgreaves National Forest, Arizona.

Fig. 19. Coarse substrate materials should be removed from samples in the field to prevent damage to the specimens.

Surber Sampler: A Surber sampler can be used to collect macroinvertebrates in spring channels with water depths of about 5 - 50 cm. Face the opening of the sampling device upstream into the current. Stabilize the net by placing one's foot on the corners. The sediment within the frame upstream of the net should be vigorously disturbed with a trowel or a probe for a specified amount of time (e.g., 1 minute), making sure to rotate and scrape all sides of the sampling area. Dislodged macro-invertebrates will passively float downstream and into the collecting device at the end of the net.

Aquatic Spot Sampling: Spot sampling is a qualitative method used for sampling shallow flows, vegetation, standing water and pools, and free-floating macroinvertebrates. A hand-net (aquarium net), D-frame net, or seive can be used to sweep up benthic or free-floating macroinvertebrates (e.g., Fig. 18).

Petite Ponar Sampling: Dredge sampling is used in lentic settings that are too deep to sample with other means, typically in deep-water limnocrene habitats. The dredge sample is hauled up, transferred to a bucket, and sieved at 0.5 to 1.0 mm mesh sieve. The area of a petite Ponar dredge is 0.023 m^2 (6" x 6").

Specimen Storage and Identification

Aquatic and soft-bodied specimens are transferred to a Whirlpack bag or a vial and usually are preserved in 70-100% ethanol. They are returned to the labora-

Fig. 20. Common springs-dependent invertebrate taxa found throughout North America, displayed using appropriate preparation techniques.

tory for sorting, enumeration, and identification. Be sure that the concentration of EtOH is sufficiently high because water from the sample may further dilute the sample. Samples collected by quantitative methods will include a mixture of substrate and macroinvertebrates, and coarse materials (Fig. 19) should be removed from the sample in the field to prevent damage to the specimens.

The bag or vial should be labeled with the site name, date, and substrate or habitat affiliation with a permanent marker, and an indelible ink label. The information also should be placed inside the bag or vial.

If quantitative samples are sorted and enumerated in the field (a less precise but more cost-effective practice), at least three individuals or diagnostic portions of aquatic macroinvertebrate morphospecies should be collected for taxonomic verification. However, specimen collection should not take place if such actions threaten or harass local populations or are not permitted.

If genetics analyses are anticipated for some specimens, the entire sample should be preserved in 100% EtOH in sterile, inert containers and stored in a dark, refrigerated environment. Because laboratory identification is time consuming and expensive, we recommend development of a voucher collection for the land management unit to expedite future Level 3 studies and monitoring. Specimens should be curated and preserved in accord with long-term museum conservation standards (Fig. 20).

Macroinvertebrates are more difficult to identify in the larval and pupal stages than in the adult stage. Therefore, it is sometimes useful to rear late-stage larvae or pupae to the adult stage for identification purposes. For example, mosquito larvae (Culicidae), caddisflies (Trichoptera) and other larval holometabolous forms (taxa that emerge from the pupal stage into the adult stage) can be collected alive, and placed in a labeled mason jar filled with stream water. Live specimens should be kept cool to minimize transport trauma. Specimens may be reared in the laboratory to the adult stage for identification. For detailed rearing instructions please consult Triplehorn and Johnson (2005) and Merritt et al. (2008).

Hydrobiidae springsnails, stoneflies, caddisflies, turbellarian flatworms, and other aquatic invertebrates are of interest as potential indicators of flow perenniality, and because species in those groups may be endemic to individual springs (e.g., Hershler et al. 2014). Collection and preservation techniques differ from those of other aquatic macroinvertebrates, and require consultation with a taxonomist. Sada and Pohlmann (2006; Appendix B: 44-45) describe collection and preservation of minute hydrobiid springsnails.

Nocturnal aquatic sampling may provide a different biological perspective of the springs invertebrate assemblage, as many taxa (e.g., leeches, Turbellaria, other Annelida, and many aquatic Hexapoda) are nocturnal and unlikely to be encountered during the daytime. Although more appropriate as Level 3 activities, the use of ultraviolet light traps and Malaise traps will result in the capture of many taxa not detected during the daylight hours, and UV light trapping in particular may be the only technique to detect some taxa, such as Trichoptera (Fig. 21).

Terrestrial Invertebrates

Collection: Documenting the use of the springs by terrestrial fauna also is important for understanding the ecological role of the springs ecosystem. A wide array of terrestrial macroinvertebrate taxa may be present, including: aerial adults of taxa with aquatic larvae (e.g., Ephemeroptera, Odonata, Plecoptera, Trichoptera, Lepidoptera, and many Diptera), and semiaquatic ochterid, gelastocorid, and saldid waterbugs.

Expert entomological taxonomy is required for the preparation and identification of various aquatic and wetland invertebrates. For example, the mandibles of cicindeline tiger beetles should be spread for ease of identification.

Prior to terrestrial macroinvertebrate collection, make sure the collecting nets are free from propagules from previously visited sites, and prepare a kill jar. Ethyl acetate (a commonly-used killing agent) can be added as needed in jars with plaster of Paris as an absorbing medium. Macroinvertebrates should be collected from all terrestrial habitat types within the spring vicinity, using the appropriate methods. Equipment used to collect macroinvertebrates will depend on the substrate type. Surveyors should collect at least three individuals or diagnostic portions of the macroinvertebrates encountered, and record any taxa observed but not collected on the datasheets. Some appropriate techniques for specimen collection and management are described below.

Sweep Net Technique: Collection on vegetation, including small trees, shrubs, grass, and annual plants is conducted using the sweep net technique (Triplehorn and Johnson 2005). To collect macroinvertebrates, swiftly swing the net back and forth through vegetation for 1 min. Each vegetation type should be collected separately and recorded on the datasheet. Once macroinvertebrates are collected, shake them to the bottom of the net and transfer them to a kill jar.

Terrestrial Spot Collecting: Spot collecting is used for macroinvertebrates that can not be collected using the sweep net technique, including those found in tree trunks, under rocks, logs or fallen branches, in leaf litter, and in flight. Small or venomous macroinvertebrates can be collected with forceps. Flying macroinvertebrates (i.e. butterflies, dragonflies, and pollinators) can be captured with a sweep net, noting host plant species, if any. A small aerial net or an aspirator is useful for collecting small flies and other invertebrates in shoreline habitats.

Beating Sheet: This method is useful for collecting invertebrates that occur on vegetation and drop off the

Fig. 21. *Metrichia nigritta* (Hydroptilidae) caddisfly mass emergence observed at Fossil Springs, Coconino National Forest, Arizona.

Fig. 22. Mites living on a captured *Argia* damselfly.

plant when disturbed (i.e., spiders, and adult stoneflies and caddisflies). Place a 1 mm or finer mesh insect net under a bush or tree, and tap the branches of the vegetation until the macroinvertebrates fall from the vegetation onto the net (Triplehorn and Johnson 2005).

Other Collection Methods: Nocturnal sampling, or the use of Malaise traps, ultraviolet light traps, colored pan traps, pitfall traps, and bait traps will reveal different terrestrial invertebrate assemblages. However, the use of these techniques is typically a Level 3 exercise.

Terrestrial Specimen Preservation and Storage: Surveyors should place specimens of hard-bodied insects (e.g. butterflies, grasshoppers, beetles, wasps) into an acetate envelope, labeled with the location, date, collector, and habitat notes. Soft-bodied or very small specimens should be preserved in ethanol with a label placed inside.

Specimen Preparation: Consult Triplehorn and Johnson (2005) for detailed mounting and pinning instruction. Hard bodied macroinvertebrates are usually pinned, while small-bodied flies and other taxa are mounted on points. Pinned specimens should be placed in sealed invertebrate boxes or drawers, and protected from pests.

Soft-bodied invertebrates, including insects, mites, spiders, and mollusks should be preserved in a capped vial filled with 70-100% ethyl alcohol, taking care that the overall concentration of preservative does not fall below 70% due to dilution by wet specimens (Fig. 22). If specimens are collected for genetic analyses, 100% ethanol and cold storage should be used to preserve the specimens.

Fieldsheet Pages 5 and 6

Vegetation Overview

Springs vegetation is usually composed of a complex of aquatic, wetland, riparian, and upland species, and can occur in profuse, diverse, and unique combinations, often with rare as well as non-native species. Vegetation characterization is conducted in relation to stewardship goals and questions, but is often the most complex and time-consuming element of rapid field inventory and assessment. However, for many study sites, projects, and most springs types, it can be highly informative. We recommend visual estimation of percent cover (VE%C) of each species in several strata to quickly and comprehensively describe vegetation composition, structure and function at springs.

VE%C methods used for rapid inventory are modified from Domin and Krajina (1933, as described in Bonham 2013), Daubenmire (1959), and Bailey and Poulton (1968). VE%C incorporates measures of vegetation composition and structure through semi-quantitative estimation of the cover of each plant species in each stratum in each microhabitat. This approach allows subtle differences in ranking to be documented. Typically, a single small individual is given a trace score of 0.01% cover, while a species with a few small individuals can be given scores of 0.1%, 0.2%, etc. Observer bias and error are still likely to occur, but the VE%C approach can provide ranked cover scores for each species, which is useful in non-parametric analyses.

VE%C requires detailed knowledge of local flora, as well as considerable practice is estimating cover, data which are least reliable when conducted casually or by novices. Cover estimation error varies between observers but decreases with experience: it may exceed 25% when conducted by novices, so training with experts is important. Many, more quantitative techniques exist for measuring and monitoring vegetation, e.g., establishment of transects, plots, or marking individual plants (e.g., Barbour et al. 1987, Bonham 2013), but such methods are more time consuming and expensive than VE%C, may miss or misrepresent rare species, and are more difficult to interpret in among-site or among-springs-type comparisons. The efficiency of quantitative techniques makes them inappropriate for Level 2 inventory and assessment, but such techniques may be appropriate for Level 3 research and monitoring efforts. Nonetheless, inventory staff collecting Level 2 VE%C should be continually aware of error related to observer bias, and should remain conservative in their practice of cover estimation. We generally find that VE%C is more accurately estimated through discussion among crew members, and with increasing experience.

Vegetation Data Collection

Once the extent of the sampling area has been determined, the team works together to agree on the number and type of microhabitats (polygons) present. The botanist should create a list of plant species on the site on the field sheet.

The botanist will then estimate VE%C for each species by cover code (stratum) in each microhabitat. Cover codes include the following:

- aquatic (AQ)—algae and emergent plants
- non-vascular (NV)—mosses, liverworts, and lichens
- basal cover (BC)—live or dead stems > 10 cm emerging from the ground
- ground cover (GC)—annual and deciduous herbaceous and graminoid plants
- shrub cover (SC)—perennial woody 0-4 m tall
- middle canopy (MC)—woody 4-10 m tall
- tall canopy (TC)—woody >10 m tall

In regions dominated by tall trees (e.g., rainforests), very tall canopy (VTC) also may be considered, but relation of VTC faunal habitat to the springs will be weak. Note that a given plant species may occupy several strata. For example, cottonwood trees may be present as seedlings (ground cover), and mature trees may occupy shrub, mid- and tall-canopy space. Also, no stratum should exceed 100% in each microhabitat.

Plant Specimen Collection

Plant species that cannot be determined on-site by the staff biologist should be documented on the field sheet with a collection number, collected, labeled with the site, date, and microhabitat, and returned to the laboratory for identification. Several individuals or diagnostic portions of unidentifiable plants should be collected. If only one individual of a species is detected on a site, it is best to photograph rather than collect it (Fig. 23). Plant specimens should include leaves, stems, roots, cones, and flowers, if possible. Plant specimens should be placed in a plant press and kept dry to prevent mold.

Algae, liverworts, mosses and other non-vascular plants can be collected for taxonomic identification. Algae are best preserved by placing the sample in filtered, buffered 3% glutaraldehyde, neutralized to pH 7 with NaOH.; or in Lugol's solution or other staining preservatives. Mosses can be hand collected and placed in an envelope for dry preservation. Aquatic plant species often are best pressed on wax paper to prevent the specimen from sticking to the pressing sheets. In the laboratory, the bags should be air dried or oven dried at 60° C for 48 hr, before identification, preparation, or curation.

Fig. 23. Photograph, rather than collect, rare unknown species encountered at the site.

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Flow Measurement Overview

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

Meinzer (1923) developed a ranking scheme for springs discharge rate, a scale that is widely used (e.g., Jay and Blair 2005) but is both illogical and incomplete: it inversely relates rank to discharge and does not well capture the range of springs discharges. The scale presented in Springer et al. (2008), augmented slightly below, uses a logarithmic SI scale to rank springs discharge rates (Table 5).

Where and When to Measure Flow: Flow measurement requires planning, both for the logistics of sampling and the equipment to be used. Springs flow should be measured at the point of maximum surface discharge, which is not likely to be the source but rather some distance downstream. The point of flow measurement should be recorded on the sketchmap (see below). Understanding flow variability is important in many situations, and flow can be expected to vary seasonally at most shallow aquifer or low residence-time aquifers. The most conservative flow measurements are made when, or in settings where transpiration losses and precipitation contributions are minimal (e.g., winter, in bedrock emergence settings). However, it is equally important to understand the impacts of riparian vegetation and groundwater withdrawal on water uptake during the growing season, so mid-summer measurements also are relevant. In short, there is no single time of year that is best for flow measurement.

Flow Measurement Techniques

General: Flow measurement techniques vary in relation to site and season (Table 3), and the SSI field sheet provides space for documenting the method(s) used to measure springs flow. Level I inventory data should help inform the team hydrogeologist as to what equipment is needed for flow measurement.

Replicated flow measurements are needed to develop a statistically credible estimate of the quantity of water discharging from the spring. We recommend that at least six measurements be made and the average value calculated. If the discharge of the spring is low (SSI's first magnitude), the discharge measurement may take dozens of minutes and should be initiated early in the site visit. Second to fifth magnitude discharge is relatively faster and easier to measure. Measurement of sixth or higher magnitude discharges (large to non-wadable channels) may take as long as or longer than unmeasurable to first magnitude measurements. The name, serial number (if available), and accuracy of the instrument(s) used to measure flow should be recorded, as well as observations of indications of recent high flows (e.g. high water marks or oriented vegetation or debris on or above the channel or floodplain).

Below we list several methods to measure springs flow, ranging from the measurement of wetted patch area when flow is unmeasurable, to timed flow capture

Table 5. Discharge magnitudes modified from Springer et al. (2008), ranges of discharge for class, and recommended instruments to measure discharge.

Discharge Magnitude	Discharge (English)	Discharge (metric)	Instrument(s)
Zero	No discernable discharge to measure	No discernable discharge to measure	Depression
First	< 0.16 gpm	< 10 mL/s	Depression, Volumetric
Second	0.16 - 1.58 gpm	10 -100 mL/s	Weir, Volumetric
Third	1.58 -15.8 gpm	0.10 - 1.0 L/s	Volumetric, Weir, Flume
Fourth	15.8 – 158 gpm	1.0 - 10 L/s	Weir, Flume
Fifth	158-1,580 gpm; 0.35-3.53 cfs	10. - 100 L/s	Flume
Sixth	1,580 – 15,800 gpm; 3.53 – 35.3 cfs	0.10 - 1.0 m3/s	Current meter
Seventh	35.3 – 353 cfs	1.0 - 10 m3/s	Current meter
Eighth	353 – 3,531 cfs	10 - 100 m3/s	Current meter
Ninth	3,531 – 35,315 cfs	100 – 1,000 m3/s	Current meter
Tenth	>35,315 cfs	>1,000 m3/s	Current meter

for small springs, the use of weirs or portable flumes for larger springs, and streamflow cross-section velocity measurement.

If less than 100 % of the discharge is captured by the flume, the percent of flow captured should be estimated and recorded for each measurement.

Portable weir plate (Wilde 2008): Weir plates are often used to measure discharge in spring channels that have low to moderate magnitude values of discharge. The weir is pushed into a channel of loose material (Fig. 24). The weir has a "V" notch, or other regular geometric shape through which all discharge in the channel must be focused, with either 45°, 60°, or 90° openings. The weir includes a stage or staff gage with the scale oriented to the upstream side and calibration of the weir plate is a function of the geometry of the notch. The 0 measurement is located at the bottom of the notch, and is used to measure the head on the weir. Using a weir plate in bedrock channels or channels with bed material coarser than fine gravel requires partially damming the channel with silt, clay, or plumber's putty while making sure not to obstruct the V notch.

Once placed in the channel, the weir is made level and plumb using a hand-held torpedo level or pre-installed bubble level. The upstream stilling pool made by the weir must first stabilize in elevation prior to measurement. Static head above the bottom of the notch is measured 6 times. The mean flow is then calculated and used in a weir flow equation to find the volumetric discharge (L/s). Portable weir plates used in measuring springs discharge need to be calibrated and have a unique coefficient of discharge variable to be used in the flow equation (Rantz et al. 1982; http://www.lmnoeng.com/Weirs/RectangularWeir.php). The flow measurement setup should also be photographed (Fig. 24).

Current meter (Wilde 2008): Current meters are used for measuring flow in wadeable spring streams or in wide channels or high discharge channels where flow cannot be routed into a weir or a flume (Fig. 25). Measurement locations are selected in a straight reach where the streambed is free of large rocks, weeds, and protruding obstructions that create turbulence, and with a flat streambed profile to eliminate vertical components of velocity. A tag line is stretched tightly across the channel perpendicular to flow, and anchored on each side.

The cross section of the channel is divided into numerous, evenly spaced partial sections, or into sections that capture equal amounts of flow. A section is a rectangle whose depth is equal to the measured depth at the location and whose width is equal to the sum of half the distances of the adjacent verticals. Measurements are made by wading the stream with the current meter

Fig. 24. Hydrologists use a V-notch weir plate to measure low volume flows in soft substrate.

Fig. 25. Current meters are best used in higher volume streams.

along the tag line. The crew member wading the channel should stand downstream of the velocity meter. Because of the safety involved in wading a channel, that individual should not wade too deeply into water and should not use hip waders in swift water without the use of a safety rope or other appropriate safety gear.

At each vertical, the following observations are recorded on the data sheet, (1) the distance to a reference point on the bank along the tag line, (2) the depth of flow, and (3) the velocity as indicated by the current meter. Velocity should be measured at 60% of the depth from the surface of water to the channel floor. The discharge of each partial section is calculated as the product of mean velocity times depth at each vertical, summed across the channel to provide total discharge.

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

Portable Cutthroat Flume: Typically, flumes are used in third to sixth magnitude discharge springs (Fig. 26). Flumes work best in low gradient channels with fine-grained bed material. The wing walls of the flume are pointed upstream in the channel in such a fashion as to focus as much flow as possible through the regular profile of the opening of the flume. The flume requires free fall of water from the downstream end of the flume.

The flume is set in a channel of loose material. A bubble level is used to make sure the flume is level. The floor of the upstream section is leveled both longitudinally and transversely. Flow is allowed to stabilize prior to measurement, and recorded 6 times and the average is calculated. A standard rating curve for the flume is used to translate gage height to discharge (Skogerboe et al. 2016). The mean value for discharge (L/s) is calculated and recorded. The accuracy of the instrument depends on the scale on the flume. A correction to the discharge measurement also should be made to account for the percent of discharge not captured by the flume.

Fig. 26. Cutthroat flumes are useful for more challenging settings. Although "portable", they are heavy and awkward for use in remote sites. This flume was used to measure flow at a rheocrene spring in Canada.

Timed volumetric (flow capture) measurement: Volumetric measurements are typically used in low magnitude discharge springs (Figs. 27-29), where flow can easily be focused into a volumetric container. A temporary earthen or plumber's putty dam is constructed to divert water through a pipe of appropriate size for the amount of springs discharge. Flow must be allowed to stabilize before the volumetric container is used to catch discharge from the pipe. The time to fill the container is recorded and measurement is repeated 6 times. The mean value is calculated (L/s) and used as the measurement. Accuracy of this measurement type depends on the calibration of the container used, and the observer's estimation of the percent capture of the springs discharge. Several pipes and calibrated containers of various sizes appropriate for first to second magnitude discharge springs should be taken into the field to ensure the best measurement possible. When not used for volumetric measurements, the containers can be used to save space and pack other field gear used for the rapid assessment. Flow at hanging gardens often is difficult to measure, but sometimes a tarp can be used to capture flow along a dripping geologic contact.

Fig. 27. Crews measure flow by creating a dam out of soil, or in this case cow feces, to direct the flow through a pipe.

Float velocity measurement: Two cross sections are selected and marked with flagging along a reach of

Fig. 28. Surveyors occasionally must improvise in order to measure flow. In this case the crew used a tarp to collect drips at a hanging garden spring on the bank of the Colorado in Grand Canyon, Arizona.

straight channel. The distance between the two sections is measured with the measuring tape. The width and depth of each channel cross section is measured and recorded. Cross section locations are separated to allow for a travel float time of >20 sec (if possible). A float (e.g., a wooden disk) placed in the stream channel and allowed to reach stream velocity before passing across the upstream line. The position of the float relative to the channel sides is noted. The float is timed between the two cross sections. This procedure is repeated 6 times, as the float is placed at different locations across the channel. The velocity of the float is equal to the distance between the cross sections divided by the travel time. The mean value of surface horizontal velocity (m/s) is calculated. To convert mean surface velocity to mean vertical velocity a coefficient of 0.85 is multiplied by the mean surface velocity. Discharge (m^3/s) is calculated by multiplying the value of mean velocity by the average area of the section of the stream channel measured. This method is less accurate than velocity measurement techniques listed above.

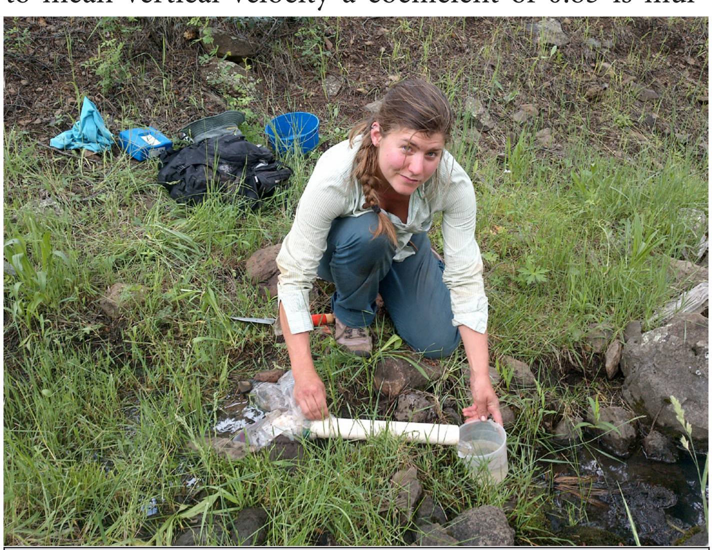

Fig. 29. This surveyor diverted flow into a pipe using a large zip-loc bag.

Depression/sump: This method is typically used for unmeasurable to low flow springs with little to no surface expression of flow, and is used as a relative comparison value of discharge. A depression is excavated within the seepage area. The depression is dewatered, and the time required to fill the depression is recorded. The filling volume is quantified using a calibrated container or similar method. This indirect, relative procedure is repeated 6 times and the mean value is recorded as the measurement at that point, recognizing that the entire surface may be seeping.

Static head change: This method may be used for a relative comparison of the change in elevation of standing pools, and is useful for measuring flow in shallow wells or vertical culverts. A metric staff gage is placed in a standing pool and surface water elevation is recorded, and the geometry of the upper portion of the pool is measured (e.g., the diameter of a vertical culvert). The pool is rapidly bailed and the recovery rate is recorded. This measurement technique may be the only means of measuring flow in standing water, and accuracy depends on the quality of the pool geometry data.

Wetted area and water table depth measurement: Helocrenes, seeps, and other springs with highly diffuse discharge are sites at which surface flow cannot be focused and directly measured. Measurement and photography of the wetted area may be the only option for estimating the extent of springs flow. Piezometers (shallow wells) are commonly installed into helocrenes for Level 3 monitoring of depth of water table.

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

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

Geomorphology

Emergence Environment: The environment in which sources emerge include:

- Cave – Subterranean sources that may only be indirectly exposed to the atmosphere
- Subaerial, by geomorphic setting- Above-ground emergence - note the geomorphic setting (e.g., floodplain, prairie, piedmont, canyon floor or wall, mountainside, etc.)
- Subaqueous-lentic freshwater- Aquatic emergence into pond or lake – note substratum (organic ooze, silt, sand, rock)
- Subaqueous-lotic freshwater- Aquatic emergence into a stream or river –note substratum (organic ooze, silt, sand, rock)

Hydrostratigraphic Unit Description: The name and rock type of the source stratum/strata of the spring source should be described. Prior to visiting the site, the geologist should review the literature on local geology and structure. If a stratigraphic column or geologic map exists, it should be reviewed and taken into the field to confirm observations.

The rock type is defined as igneous, metamorphic, or sedimentary and the sub-type described. The size and shape of individual grains that comprise the rock can be described: if the grains are large enough, the size can be estimated with a mm ruler, but if the grains are small, a hand lens can be used to examine the size and shape of minerals comprising the rock for the description of the rock. A drop of 10% HCl can be placed on a fresh, unweathered surface to discern if the minerals or the cement of the rock are comprised of carbonate (if so, the wetted surface will fizz). A rock color chart is consulted to describe the color of the rock. If it is uncertain what the type of rock is or the name of the stratigraphic unit, and if an appropriate permit is secured, a sample of the rock should be collected and analyzed in the laboratory. If a rock is collected, the date and site location should be recorded on the rock with a permanent marker. If the sample is poorly consolidated, it should be placed in a sample bag labeled with the site location information and date.

Flow Forcing Mechanisms: The forces that bring water to the surface may not be evident on a single visit, or without information on subsurface water from surrounding wells. If the forces that bring water to the surface are evident, they should be described. Typically, most springs are gravity fed. Artesian springs discharge water under pressure, or may issue from an aquifer that has an upper confining layer, subjecting the flow to fluid pressures in excess of the pressure due to gravity at the point of discharge (Fig. 10). Thermal springs emerge when groundwater comes in contact with magma or geothermally warmed crust and is forced, sometimes explosively in geysers to the surface (Fig. 11). Some springs do not flow and are not subject to pressurized discharge (Fig. 10), while others have multiple forcing mechanisms. Anthropogenic factors, such as groundwater loading around large reservoirs, may create forces that anthropogenically affect springs emergence. One of the following mechanisms should be recorded along with additional notes. Note that additional data may be needed to determine the forcing mechanism.

- Gravity driven springs—Depression, contact, fracture, or tubular springs
- Artesian springs-—Increased pressure due to gravity-driven head pressure differential
- Geothermal springs—Springs associated with volcanism
- Springs emerge due to pressure produced by other forces—e.g., coke bottle springs are driven by constant gas build-up and release
- Springs due to pressure produced by anthropogenic forces—Anthropogenic artesian or geyser systems (e.g., hot springs associated with Hoover Dam, Arizona-Nevada)

Source Geomorphology: Groundwater may be exposed or flow from filtration settings (poorly consolidated, permeable materials), or from bedrock fracture joints, or solution passages. Also, a spring may exist as groundwater exposed at the surface, but which does not flow above land surface. An additional type is a stratigraphic contact environment in which springs such as hanging gardens emerge along geologic stratigraphic boundaries. Following are the forms of sources:

- Seepage or filtration spring--Groundwater exposed or discharged from numerous small openings in permeable material

- Fracture spring-- Groundwater exposed or discharged from joints or fractures
- Tubular spring-- Groundwater discharged from, or exposed in openings of channels, such as solution passages or tunnels
- Contact spring-- Flow discharged along a stratigraphic contact (e.g., a hanging garden)

Springs Runout Channels: The morphology of the channel is examined (if a channel exists) to determine if it is spring-dominated or surface-flow dominated. If a channel is springs-discharge dominated, the channel often is nearly bankfull at baseflow conditions. If the channel is surface-flow dominated, typically the channel is oversized for the baseflow of the spring. Typically there are two bankfull stages for surface-flow dominated channels; a small, incised channel for baseflow condition, and a larger, wider channel created by regular surface flooding (Rosgen 1996).

If a spring channel exists at the site, the slope, channel width, depth, sinuosity, substrate, and channel type should be measured and/or described. The slope is measured with a clinometer over its distance. The width of the channel is measured from the top of the bank on river left to river right. A measuring tape should be stretched across the channel and secured. In the center of the channel (the thalweg) the depth from the stretched tape to the bottom of the channel is measured to record the depth of the channel. Width and depth should be measured at 3 to 5 locations within the springs-dominated channel or one meander of the channel. The distance between the two meanders should be measured with the measuring tape (or paced if the distance is greater distance than the tape). The size and shape of the clasts in the channel should be described using the substrate particle size scale. If the channel is directly on bedrock, the name of the rock unit should be recorded.

Table 6. Chemical parameters, instrument type, detection limit, sample preparation and recommended sample handling times.

Chemical Parameter	Instrument	Detection Limit	Sample prep	Handling Time
18-Oxygen (^{18}O)			No filtering or preservation required	28 d
2-Hydrogen (^{2}H)			No filtering or preservation required	28 d
Nitrogen – Ammonia (NH_3)	Tehnicon Auto Analyzer, or comparable	0.01-2mg/l NH3-N	Filtered, 4	2 d
Phosphorus (PO_4^{-3})	Tehnicon Auto Analyzer, or comparable	0.001-1.0 mgP/l	Filtered, 4	2 d
Nitrate - Nitrite (NO_3^-)	Tehnicon Auto Analyzer, or comparable	0.05-10.0mg/L NO	Filtered, 4	2 d
Chloride (Cl^-)	Ion Chromatograph	0.5mg/L and higher	Filtered, no preservation required	28 d
Sulfate (SO_4^{-2})	Ion Chromatograph	0.5mg/L and higher	Filtered, no preservation required	28 d
Calcium (Ca^{+2})	Flame Atomic Absorption Spec.	0.2-7 mg/L	Filtered, HNO	28 d
Magnesium (Mg^{+2})	Flame Atomic Absorption Spec.	0.02-0.5 mg/L	Filtered, HNO	28 d
Sodium (Na^+)	Flame Atomic Absorption Spec.	0.03-1mg/L	Filtered, HNO	28 d

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Water Quality Overview

Field and laboratory water geochemistry methods are described by the U.S. Geological Survey (reviewed in Wilde 2008; Table 6) and endorsed by the Environmental Protection Agency. Air and water temperature, pH, specific conductance, electrical conductivity, total alkalinity, and dissolved oxygen concentration are commonly measured using daily-calibrated field instrumentation. Water quality samples and measurements are made at the springs source, rather than downstream from the source, to capture to the extent possible the characteristics of the emerging groundwater. Individual devices often are designed to measure multiple parameters (e.g., multimeters), but each probe needs to be calibrated against laboratory standards each day. Water quality kits can provide backup measurements when electronic units inevitably fail at remote sites (Fig. 30).

Filtered 100 mL water quality samples can be collected in triple acid-washed bottles for laboratory analyses of major cations, anions, and nutrients, if such analyses are among the project objectives. One to two filtered water samples can be collected in 10 mL acid-washed bottles for stable isotope analyses. Water samples used to test for nitrogen and phosphate concentrations should be returned to the laboratory for analysis within 48 hr of sample collection. Water quality samples are stored on ice, but not frozen, following standard sample storage and time-to-analysis protocols. One note - in our experience, the more expensive the sampling device, the more likely it is to malfunction in remote field settings. Therefore, contingency planning is recommended, with several backup devices or strategies for obtaining water quality information, particularly for remote sites.

Field parameters: Field water-quality measurement of specific conductance (uS/cm), pH, temperature (°C), and dissolved oxygen (mg/L) should be conducted following U.S. Geological Survey and Environmental Protection Agency protocols (Wilde 2008). For example, an *InSitu*, Inc. Troll9000 or YSI multi-parameter water-quality meter with hand-held Rugged Reader and quick calibration solutions can be used. These instruments are light-weight and portable and, with additional probes, can be used to measure oxidation reduction potential, salinity, depth, barometric pressure, nitrate, ammonium, chloride and turbidity if these field parameter data are needed. Alternatively, an electrical conductivity (EC), pH, and temperature meter, or equivalent can be employed for field measurements.

Fig. 30. Test kits are available to accurately measure water characteristics such as alkalinity. These require no calibration, are relatively inexpensive, and provide a useful backup system for electronic units.

Calibration of the instrument should follow manufacturer recommendations. At a minimum, the instrument should be calibrated daily. A separate log book should be kept with the instrument with calibration information. The pages from the calibration log book should be copied and included with the field data form.

Field water-quality measurements from flowing water sites should be from discharge areas with uniform flow and stable bottom conditions (Wilde 2005, 2008). Field water-quality measurements from stillwater or pooled sites can be taken using spatially distributed vertical profiles; however, such standing waters at springs likely will be altered by atmospheric conditions and may not well reflect groundwater quality.

Laboratory Water Quality Measurement: Prior to fieldwork, wash the appropriate and extra 100 mL and 4 mL polyethylene bottles in HCl acid three times and rinse with deionized water. After washing, allow the bottles to air dry and then cap them. Label each bottle with a distinctive color of labeling tape to distinguish treatments, if needed. Record the site, date, and treatment on the label during field data collection.

Latex gloves and safety glasses should be worn for water quality sampling. Filter, fill and rinse the sample container with water from the spring three times before collecting the sample. Do not contaminate the inside of the sampling container or the lid.

Samples should be stored on ice in the field but not frozen, and transferred to a refrigerator and stored at 4° C, then delivered to a certified analytical laboratory for processing. PO_4^{-3}, NO^{-3}, and NH_3 should be processed within 48 hours of collection, following USGS and EPA standards, while cation and anion analyses should be undertaken within 28 days. Analyses are conducted using automated color imagery techniques or other appropriate analytical equipment (Table 4). Flame atomic absorption spectrophotometry should be used to analyze Mg^{+2}, Ca^{+2}, and Na^{+}. Ion chromatography is used to analyze PO_4^{-3}, NO^{-3}, and NH_3 (Table 5). Appropriate duplicate samples should be collected as controls (typically one in 10 samples are double-collected).

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Springs Ecosystem Assessment Protocol (SEAP)

The U.S. Environmental Protection Agency, Army Corps of Engineers, and state water quality offices protect ground and surface water quality, wetland ecosystem health, and relevant ecosystem, sociocultural resources and impacts, and other natural and social aquatic and wetland ecosystem functions as needed (e.g., Cowardin et al. 1979; U.S. Army Corps of Engineers 1987; National Research Council 1992, 1994; Federal Geographic Data Committee 2013; NWI 2015).

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

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

Additional

Socio-cultural and Historical Inventory

Springs play important roles in local and regional indigenous cultural landscapes, in history, and in socioeconomics, roles that are poorly known outside the Tribes. Documentation and archival of such information may be useful for ensuring thoughtful springs stewardship; however, sociocultural information on springs is the intellectual property of the steward(s), and should be collected and compiled as protected sensitive information. Categories of historical and sociocultural information can be assembled through review of the literature and through interviews with springs owners or the leaders and elders of managing Tribes. Such information may include a wide array of ethno-environmental, economic, religious, historical, and traditional ecological knowledge and data. The Level 2 field form provides a context for documenting components, processes, and characteristics important at individual springs, through check-boxes and comment boxes. These are recorded in the database, which also can document and hyperlink to other forms of information, including photographs, videography, and recordings of interviews. Thus, the Level 2 inventory database is designed specifically to provide Tribal springs stewards with a secure means of archiving critical cultural and historical information that may otherwise be lost over time.

After Field Work

Specimen Data Management

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

Invertebrates: Once separated from matrix materials in the laboratory, specimens are initially sorted into morpho-taxa and identified to order. Hard-bodied macroinvertebrates are pinned or transferred to separate envelopes, and aquatic macroinvertebrates should be transferred to individual vials with ≥70% ethyl alcohol distinguished by order. Subsequently, macroinvertebrates are identified to lower taxonomic levels, preferably to the genus or species level by an accredited taxonomist and using North American taxonomic keys (Thorp and Covich 1991, Triplehorn and Johnson 2005, Merritt et al. 2008). If quantitative samples were collected, macroinvertebrates should be enumerated and density (species/m^2) should be calculated.

Each specimen should be accompanied with a label with the site name, date, substrate or habitat affiliation, taxonomic name of the macroinvertebrate, and the first name initial and full last name of the collector. Final collection labels for macroinvertebrates should be typed and printed on 3-5 pt. font on high cotton content, white paper no more than 6 x 15 mm in size (Triplehorn and Johnson 2005). Labels should be placed below the macroinvertebrates for pinned specimens and inside vials for alcohol preserved specimens. Specimens should be properly curated in a dark, cool environment, and databased.

Vegetation Data: Several features of the database aid in vegetation data entry, error checking, and reporting. Plant species taxonomy, nativity within biomes, and wetland status are archived in the database in a look-up table that automatically prevents taxonomic typographic errors during data entry. VE%C by microhabitat, stratum, nativity, and wetland status are summarized by species, by stratum, and by functional group in an automated report within the SIP database, saving a great deal of analytical and reporting time. SSI's Springs Online database distinguishes "stratum taxa" from total species richness in the automated vegetation reports.

Vegetation cover estimates are used to frame the SEAP analysis of habitat extent, quality, and function (see SEAP section, below). Along with the extent of non-native species cover and species richness, the database automatically reports many components of habitat structure and function based on vegetation characteristics of the site. When a large number of springs have been analyzed for vegetation, it will be possible to refine our understanding of the complex interactions among soils, aspect, elevation, climate, and biogeographic affinity on springs vegetation and habitat structure.

Equipment Maintenance

Tools, parts, and materials used while conducting field work for many dozens of springs over many weeks will undoubtedly require more corrective and preventive maintenance. Sensitive electronic equipment such as GPS units, field computers, satellite phones, radios, and water quality testers need to be properly stored in accordance with manufacturer instructions. This often entails replacing of water quality tester electrodes and storing in a special storage solution, software updates for GPS units and computers, and general battery maintenance of radios.

Vehicles also sustain damage and wear from transporting the survey team across sometimes vast landscapes during springs inventories. During the spring and summer seasons in the southwest, weather is highly unpredictable with temperatures often exceeding 100° F, and thunderous monsoons can leave backcountry and forest roads washed-out or inundated with water and extremely muddy and difficult to navigate. Because of the varied and often harsh conditions survey vehicles are put through, preventive and corrective maintenance should be of the highest priority. This entails regular oil and filter changes, checking of tire tread wear, thorough cleaning of undercarriage and engine compartment, and general cleanliness of the cab and truck bed. All field equipment should also be washed and sterilized following the protocols set forth earlier in this document.

Information Management

Overview: Level I and Level 2 inventory protocols are developed on the assumption that the steward(s) will undertake and maintain a long-term information management program. In the case of large landscape management units (national parks, forests, Tribal reservations, etc.), such information management systems should be related to the steward's geodatabase and geographic information systems. Such stewards are likely to have data archival, site photography, specimen curation, and clearly defined metadata and reporting standards.

The SSI Springs Online information management system and its metadata are secure, easily accessed, easily reported upon, and readily allow for additional or new analyses. No other such data management systems presently exist for springs ecosystems, but the long-term value of such information management systems is the protection and sharing of data with other springs ecosystem managers within aquifers. We present a comprehensive, relational springs database and information management system, along with commonly requested auto-formatted reports.

All data, photographs, the sketchmap, and other information about the biology of each variable and the overall springs ecosystem monitored should be entered into a relational database as soon as possible while the survey crews still remember the sites. Springs Online database at http://springsdata.org/ provides a free, online, secure, easy-to-use, and comprehensive springs information management system.

Photo and Sketchmap Management: Image processing is given highest priority after returning from field work to make data entry more efficient and to assure that they are not misplaced. The crews should organize all photographs into folders labeled for each site. Images must be less than 1 megabyte to be uploaded into the Springs Online database. Using Adobe Photoshop or similar photography editing software, macros can re-size images in batches. Although it is helpful to rename image files to identify specific subjects, and to include the name, maintain the original photo numbers in the file names as those are documented on Page 1 of the field sheets.

Sketchmaps should first be quality checked for any discrepancies (e.g., correct polygon area totals, scale bars, north arrows, surveyor names, etc.) and then scanned and saved into their respective folders. Sketchmaps also must be less than one megabyte in size to be archived in the Springs Online database, and are best saved in jpeg format.

Quality Assurance/Quality Control: Quality control analyses of data entered into such a system should be conducted using standard methods (Ledbetter et al. 2014, described at: http://springstewardshipinstitute.org/). A well-designed database should only archive monitoring data, but also produce automated reports on the condition and trends through time of focal variables. Such database capacity vastly simplifies regular reporting and conserves staff time.

Data quality control for data accuracy and entry is the responsibility of the crew supervisor. Field data are entered into the Springs Online database immediately upon return from the field, and field data should be preserved in electronically scanned or hard copy formats. The SSI Springs Online inventory database (www.springsdata.org) is designed to flag outstanding values for many variables and to maximize veracity of the data. All data entry should be overseen and checked by the project supervisor or the information manager. Data entry errors and data checking should be documented and corrected.

QA/QC is documented in three ways in the Springs Online database. Field forms contain fields to document completion of data entry. The site form "History" tab documents who has made changes to that site. The surveys form "QA/QC" tab documents the history of data changes as well as the name, date, and comments related to QA/QC. The Springs Online database automatically tracks changes to data with a date stamp and a login name. Standard QA/QC verification of data accuracy should be conducted on, and reported for at least 5% of the data entered.

All hard copy documents should be safely archived (scanning is preferable), and should remain available for future reference. If copies are made of original documents, the copies should be clearly legible. QA/QC on specimen collections are warranted.

Other recommendations

The responsibilities of the inventory crew continue after returning from the field, including equipment maintenance, restocking of supplies, specimen organization and preparation, and data entry. Follow-up with volunteers and stakeholders is another crew responsibility, and may include communication updates, status reports, revelation of discoveries, and thank you notes. Attention to these tasks will help keep the project on schedule. State and federal agencies will sometimes require trip reports. Publication of results should be the end goal of any scientific endeavor, and the staff and administration should take appropriate steps to pursue that goal.

Level 3 Inventory

Overview: Level 3 springs work is conducted on sites that are: the focus of monitoring; socio-cultural or economic protection; research; or sites at which ecological rehabilitation is undertaken (e.g., Biebighauser 2015). Several tasks are commonly undertaken at Level 3 sites: 1) administrative coordination to guarantee long-term funding and logistical support; 2) management and archival of existing and background information; 3) the production of a detailed land survey map of the springs, on which to organize prioritized stewardship actions; 4) long-term flow and geochemistry monitoring is conducted; and 5) development of a groundwater model is undertaken to predict variation in discharge, geochemistry, pumping impacts, and climate change effects. General monitoring can be accomplished using Level 2 inventory techniques, and additional monitoring methods may be warranted depending on the long-term data needs. Because long-term studies are rare and highly context-specific, we do not attempt to prescribe protocols for Level 3 efforts here. Rather, we direct the reader to the synopses of research conducted at Silver Springs (e.g., Kemp and Boynton 2004), Montezuma Well (Blinn 2008), and Yellowstone Hot Springs, where detailed Level 3 studies have been undertaken. Elements of Level 3 monitoring are described below.

Monitoring

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

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

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

What to Monitor

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

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

When to Monitor

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

Monitoring Plan Elements

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

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

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

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

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

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

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

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

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

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

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

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

Biological Monitoring

Vegetation: Level 2 inventory methods are appropriate for documenting vegetation change through time. Several metrics can be calculated from the Level 2 data and used for trend assessment. The SSI database auto-calculates plant species density by dividing the number of plant species by the area of the geomorphic microhabitats and that of the entire site. In addition, the database calculates the percent cover and species density of native wetland plant species and nonnative plant species in accordance with the USDA-PLANTS database (2013).

Macroinvertebrates: Invertebrates should be collected at each site using spot sampling for a period of at least 15 minutes during the monitoring visit. Spot collection techniques include general collecting, dip-netting, and aerial netting on the site's various microhabitats. Nocturnal site visits often are useful for detecting species that may not otherwise be observed. Nocturnal ultraviolet light trapping also can be used to collect adults of some groups (e.g., caddisflies) that may not otherwise be detected. Seasonal nocturnal, spot, ultraviolet light, Malaise, and pitfall sampling should be considered for the first several years of monitoring to establish the range of natural variation and, if warranted, at 3-5 year intervals thereafter to evaluate trends in macroinvertebrate species composition and density.

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

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

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

Special Monitoring Elements

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

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

Monitoring of vertebrates at springs should be conducted systematically, and trends over time can be determined. Fish monitoring usually involves indirect sampling intensity-based capture per unit effort (CPUE) methods or direct density estimation using seining, backpack-electroshocking, snorkeling, or SCUBA. Amphibian and other herpetofaunal surveys and monitoring are most efficiently conducted using non-lethal "light-touch" visual surveys, in which surveyors gently explore suitable habitats, turning over and replacing logs, rocks, or artificially-installed habitats (e.g., plywood boards). In addition, they may use temporary pit-fall traps to locate or capture herpetofauna (O'Donnell et al. 2007). Point-count methods are standard for avian monitoring (US Fish and Wildlife

Service 1999: http://www.fws.gov/mountain-prairie/migbirds/avian_monitoring.pdf). Live trap sampling population assessment, and disease vector monitoring methods have been developed for small mammals (e.g., https://clu-in.org/download/ert/2029-R00.pdf). Genetics sampling methods also are sometimes used to evaluate population viability of vertebrates, using samples of blood or tissue from animals that are collected, or from hair or feces collected randomly or along transects (https://en.wikipedia.org/wiki/Genetic_monitoring#Estimating_abundance_and_life_history_parameters_.E2.80.93_Category_Ia).

Equipment Sterilization

On leaving the monitoring site, surveyors should sterilize shoes, nets and other items to prevent spread of chitrid fungus, other disease microorganisms, and nonnative species. Appropriate sterilization methods for clothing, equipment, and vehicles are found at: http://johnsonlab.byu.edu/Portals/80/docs/Field%20Gear%20Disinfection.pdf. That website reported that "the most effective products for [sterilizing field equipment and clothing to prevent chitrid fungus dispersal] were Path-XTM and the quaternary ammonium Compound 128, which can be used at dilutions containing low levels of the active compound didecyl dimethyl ammonium chloride. Bleach, containing the active ingredient sodium hypochlorite, was effective at concentrations of 1% sodium hypochlorite and above. Didecyl dimethyl ammonium chloride at a concentration greater than 0.0012% for 2 min., or sodium hypochlorite at a concentration greater than 1% for 1 min. are effective treatment procedures." However, high concentrations of sterilization fluids also pose a threat to springs biota, so we also recommend post-sterilization rinsing with clean water.

Reporting

Individual Site Description

SSI's online database generates site specific reports automatically once the survey data have been uploaded, and relevant data fields are populated. These survey summary reports include: the location with all georeferencing and geographic data, as well as the names of the survey team, the date and start and end time for the survey; the physical description detailing the spring type, its source, springs microhabitats, geomorphic diversity, available solar radiation, emergent environment, and flow force mechanism; survey notes that include the condition of the site; flora data that includes vegetation cover types and percent cover along with the botanists' name(s), species nativity, and collections; fauna data including invertebrate and vertebrate species richness; assessment information categories from the SEAP and defining the risk and condition of site specific biology, geomorphology, aquifer functionality and water quality, habitat, and human influences; and representative and additional photos of springs sources, flow measurements, and sketchmaps. Push-button reporting vastly simplifies report generation and export in Microsoft Word format, and allows project managers flexibility in editing.

Landscape Analysis

This analysis compiles all of the individual springs data from a project into a single document detailing all inventories undertaken and includes multiple maps of springs distribution across the project area. The results of this analysis explain the total number of springs inventoried, improving georeferencing of springs locations, the average and median area of springs surveyed, and the total number of reported springs. From this total and surveyed springs median areas, we can indicate how much springs habitat exists within a landscape.

Water quality is summarized and explains the general trends of observed during surveys. This is also included in an appendix for the land manager's reference. Vegetation inventories are compiled into tables summarizing plant species richness by nativity and functional group. Vegetation data is also used to extrapolate the plant species densities per hectare from the given area of habitat inventoried. This also helps to document the approximate percentage of vegetation that occurs at a landscapes springs; this most often makes up a very small percentage of the total habitat within a landscape and demonstrations the disproportionate role that springs have in the context of vegetation distribution. Total wildlife inventories are also summarized and are available to managers as individual site reports.

SEAP methods and results (described separately at springstewardshipinstitute.org) conclude this analysis with the risk and condition scores for each springs plotted in a graph to represent the springs that warrant the most immediate management attention. Managers can use this analysis to apply limited resources to those springs that have the greatest potential for improvement. Individual SEAP scores for the 6 categories and 42 subcategory variables are also provided for detailed analysis of stewardship issues.

Trend Detection

Trend detection is a valuable and often crucial part of monitoring, and such information can be readily exported for any site or project from Springs Online. Many of the variables used in trend detection at springs ecosystems are influenced by seasonality. Therefore, caution is warranted when attempting to draw conclusions based on comparison among a small number of repeated site visits. Some variables may not be appropriate monitoring metrics at some springs or spring types.

Site and Project Reporting

Some gushet and hanging gardens, and most rheocrenes are subject to flooding, and variables like vegetation cover may be highly dynamic. Grand Canyon Wildlands Council (2004) reported that wetland vegetation cover varied from 20 - 80% over three years at one gushet springs. Such variability indicates that vegetation cover is not a useful monitoring metric at such highly dynamic springs.

A user can download a summary report for a springs ecosystem, a summary report for a specific survey from that springs site, or a report for all the springs in a project. These reports can include the overall information from the spring site as well as summaries of each survey recorded. Files should be in .doc format. Users also can export a spreadsheet or crosstab of all the flora species observed during a site survey. This crosstab includes species names, vegetative cover codes, percent cover per polygon, and nativity and wetland status. A vegetation cover summary page can be created that includes total percent cover per polygon and per cover type, species count per polygon, species density/m^2, nativity, and wetland species per stratum, along with total values. Flow and geochemical trends similarly can be exported and reported upon.