Spring Ecosystem Inventory Protocols

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Contents

Introduction

Spring 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 often refer to these features in the plural form.

Fed by groundwater aquifers, springs occur in many settings, both underwater and in terrestrial environments. Springs vary greatly in flow rate, water chemistry, geomorphic form, ecological significance, and cultural and economic importance (Springer et al. 2008, Springer and Stevens 2009, Stevens et al. 2021). Seeps are simply small springs, usually with diffuse or unmeasurably low discharge.

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. 2015), critical water supplies, keystone ecosystems (Perla and Stevens 2008), refugia for rare or unique species (e.g., Shepard 1993; Scarsbrook et al. 2007; Hershler et al. 2014, 2015), remarkable paleontological repositories, as well as social and economic 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 spring form and function as socio-ecosystems, or to develop coherent and integrated protocols for ecological inventory, data management, and stewardship. 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). However, few springs have been studued as ecosystems. Exceptions include 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 spring 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, Sistiaga et al. 2020) and have intensively used springs for millenia for ambush hunting, harvesting plants and minerals, and of course for reliable sources of drinking water (Haynes 2008). However, modern human uses of springs and their immediate surroundings have become far more complex and now include groundwater pumping, flow diversion and irrigation, mining, livestock husbandry, silviculture, and recreation. Some of these uses have affected ecological integrity of springs by contributing to pollution and erosion, changing spring discharge rates, and introducing nonnative species, leading to other direct and indirect changes to the spring ecosystems. Many of these effects are ubiquitous, occurring across broad regions and at all springs types, while other changes are specific to certain springs or types of springs. Nevertheless, with thoughtful aquifer and land management, much damage to spring ecosystems can be easily avoided. Because human use of North American springs extends over the past 15,000 years, springs stewardship planning must include consideration of human use as well as ecological sustainability.

Human use of groundwater can lead to flow reduction or even complete dewatering of springs, with impacts manifesting at local to regional scales. Flow reduction results in substantial alteration of springs microhabitats, vegetation composition and cover, and faunal occurrence and distribution. It can also lead to 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 spring sources can reduce or eliminate surface expression of flow, jeopardizing ecosystem structure and function.

In contrast to regional effects, some impacts are likely to occur at specific springs types. For example, gravel mining is most likely to affect rheocrene springs, while trenching, flow focus, and excavation are common practices at marsh-forming helocrene springs (e.g., Fig. 2). Understanding general and specific types of impacts is important because springs often serve as keystone ecosystems, and degradation can reduce the ecological integrity of adjacent upland ecosystems as well as the springs themselves.

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

Anthropogenic manipulation of spring sources commonly includes partial or complete diversion of water and the construction of springs boxes. Environmental Protection Agency (EPA) and state policies require that groundwater used for domestic purposes be captured prior to emergence, to ensure that it is not contaminated by exposure to the atmosphere. However, this practice can eliminate the source area—the most biologically important habitat of the spring 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 (Gurrieri 2020). Thus, spring 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., Kodric-Brown and Brown 2007, Gurrieri 2020).

In spite of the importance of and threats to these resources, springs have yet to receive substantial attention or protection from most water or natural resource managers or policy makers; the U.S. Forest Service is a notable exception. Little attention has been paid to springs ecosystems in any major technical review or textbook on national water resources in the past three 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, Kreamer 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, Stevens et al. 2021), 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).

Springs as Socio-Ecosystems

While springs receive less attention than deserved in the realms of ecological research and management, the societal regard for springs as ecologically, socially, culturally, and spiritually important landforms is widespread (e.g., Nabhan 2008, Rea 2008, Phillips et al. 2009). But even in the social, economic, and anthropological disciplines, there is little formal research on springs. Few recent regional inventories of Indigenous cultural attributes of springs been systematically conducted (but see Canaan 1922). Neither have the ecological economics of springs been much explored. In one of the few analyses conducted in the United States, 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. Wu et al. (2018) surveyed visitors of four large Florida springs in 2016 and estimated the recreational value of the four springs at $25 million. They also found that on average, vositors were willing to contribute an additional $12 to $14 per trip for springs restoration. Gleick (2010) reported that 80 million bottles of water were sold every day in the United States, many of which are labeled as "spring 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 ecosystem and landscape functions, as well as goods and services for humans. In general, if the aquifer is intact, the spring ecosystem it supports is 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 good stewardship, but far too often we have encountered springs that have been unnecessarily destroyed by poor management and neglect. With the recent clarification of spring classification and ecosystem information needs (Stevens and Meretsky 2008, Stevens et al. 2021) and the development of this inventory protocol, we are contributing to the development and standardization of spring ecosystem research, inventory, and assessment, with the ultimate goal of improving stewardship. Our perspective is that we should work towards improving scientific understanding of the ecology of springs, and that springs used for human purposes should be sustainably managed for both societal and ecosystem functionality whenever practicable.

Springs Ecosystem Conceptual Model

Stevens and Springer (2004) and Stevens et al. (2021) proposed a general conceptual model of spring ecosystems (Fig. 3). It is a primarily bottom-up ecosystem model with external physical variables, such as climate

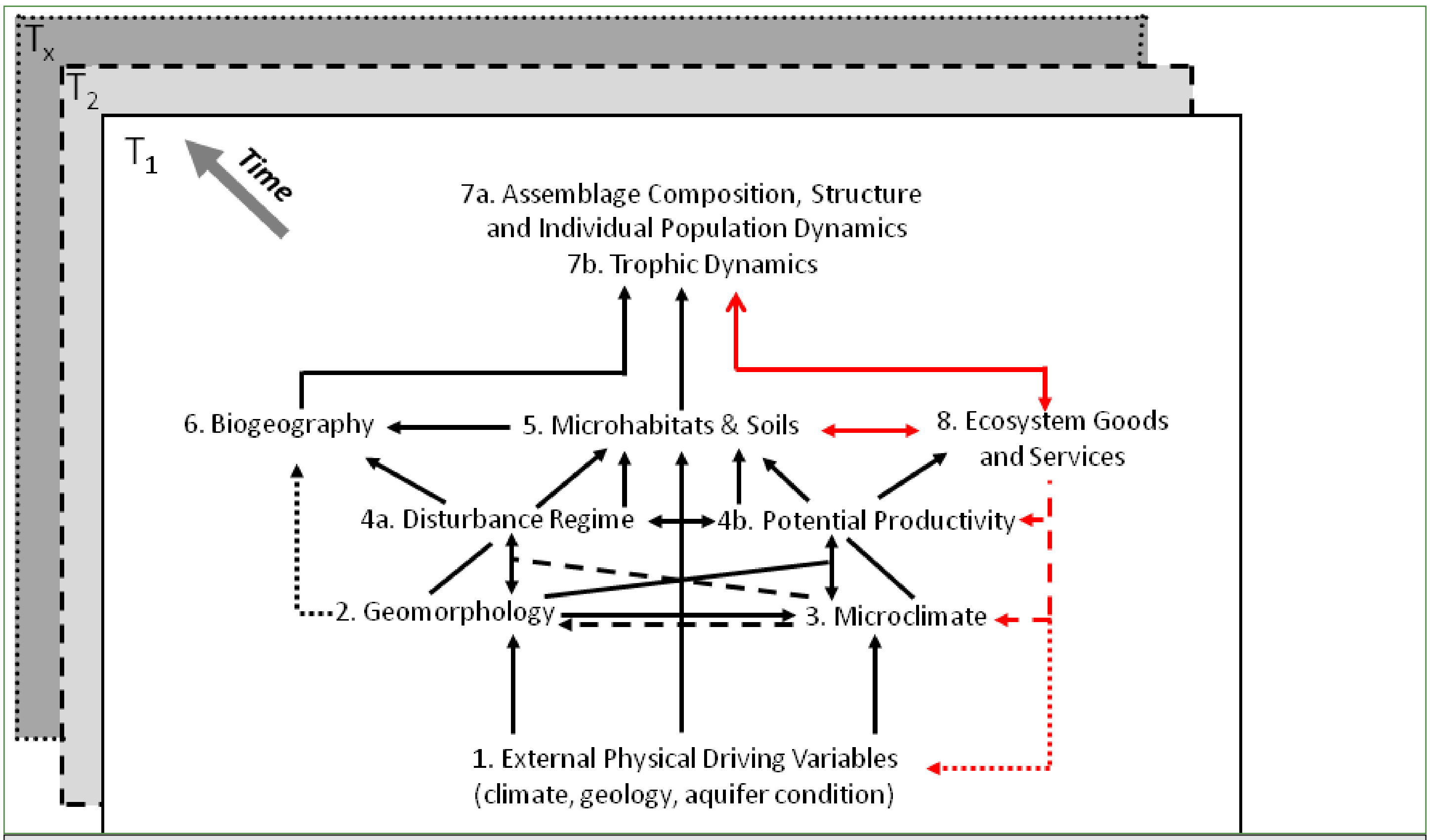


Fig. 3. Springs ecosystem conceptual model (modified from Stevens and Springer 2004). Dashed arrows reflect indirect influences, while red arrows indicate human impacts.

and aquifer, driving local physical variables, such as geomorphology, microclimate, discharge rate, water chemistry, and the disturbance regime. These local physical variables together define the microhabitats at the site, which in turn shape biotic interactions. At the same time, human uses exert top-down influences on all levels of the model.

While not yet fully tested and quantified, this conceptual model forms the framework around which the SSI Springs Inventory Protocol was designed. Following this bottom-up dynamic, surveyors record data on a variety of local physical variables including discharge rate, water chemistry, local geomorphology and soils; use that information to define and map microhabitats; and document the vegetation community according to microhabitat affiliation. Surveyors also record wildlife use of the site with notes on specific habitat use (Fig. 4, Fig. 5). Evidence of recent, historic, and prehistoric human use of the site (the model's top-down component) is carefully described as well. This primarily bottom-up model also supports the use of site geomorphology as the primary factor in the springs classification system described below (Springer and Stevens 2009, Stevens et al. 2021). In addition to providing a conceptual foundation for the spring inventory methods and a spring classification system, the model also informs spring ecosystem assessment, stewardship activities, and monitoring.

Fig. 4. Sampling for rare invertebrates at a spring-fed pond near the north rim of Grand Canyon.

Springs Classification Systems

Improved stewardship of springs requires a definitive classification system because springs ecohydrology, management, development, and restoration options all vary in relation to springs type (Kreamer et al. 2015, Stevens et al. 2016, Sinclair 2018, Stevens et al. 2021). Identification of rare springs, systematic assessment of ecological integrity, variation in microhabitat distribution, and the distribution of rare, endemic or endangered springs-dependent species all are central natural resource management concerns that require knowledge of the springs type. Springs are highly individualistic ecosystems that vary widely in many features, and a definitive, widely accepted global springs classification system is essential to improve basic scientific understanding and ecosystem stewardship.

The history of springs classification extends back more than a century, with attempts to classify springs by Fuller (1904), Thienemann (1907, 1922), Keilhack (1912), Waring (1915), Bryan (1919), Meinzer (1923), Clarke (1924), and Stiny (1933). Meinzer (1923) identified 11 different suites of variables through which to classify springs, and various authors have proposed other useful classification schemes (see Glazier 2014 for a summary of 46 such schemes). These can be grouped into seven general conceptual approaches, including those focused on characteristics of: 1) the aquifer, 2) springs discharge, 3) water quality (temperature, geochemistry), 4) landscape position, 5) local site geomorphology, 6) vegetation, and 7) combinations of those variables (reviewed in Springer and Stevens 2009). All of these approaches have their respective merits, but the most widely used and definitive approach to classifying springs ecosystem types is through geomorphology.

Traditionally, hydrologists have classified the physical geomorphology of springs at the point of emergence

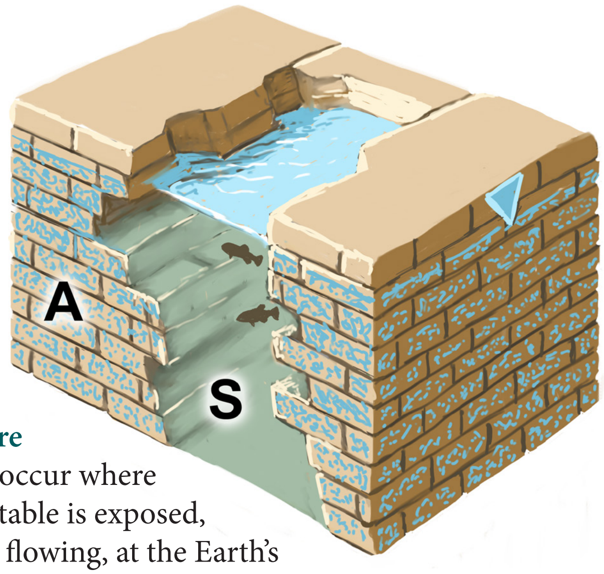
Fig. 5. Springsnails *(Pyrgulopsis sp.)* are often locally endemic to springs ecosystems. These specimens of a possibly new species were collected in the Spring Mountains National Recreation Area in Nevada.

only (e.g., Bryan 1919; Meinzer 1923, Thienemann 1907, 1922). Alfaro and Wallace (1994) and Wallace and Alfaro (2001) and Glazier (2014) reviewed those historical spring classification schemes. Springer et al. (2008), Springer and Stevens (2009), and Stevens et al. 2021 expanded the early geomorphological characterization to include 12 discrete types of terrestrial springs, not including fossil paleosprings (i.e., springs that flowed in the geologic past, but that no longer flow). Now, after more than a century of spring, stream, and wetland classification efforts, the only definitive geomorphic classification system for springs is that of Springer and Stevens (2009; updated in Stevens et al. 2020), summarized here. Table 1 is a dichotomous key for the 12 springs types, and Fig. 6 and Fig. 7 on the following pages include a cartoon sketch and brief description of each spring type.

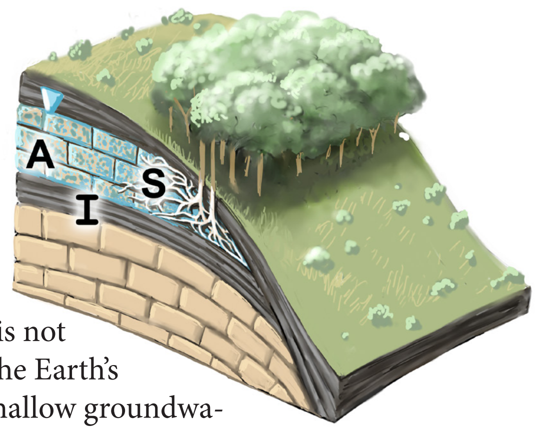
Table 1. A dichotomous key to terrestrial springs types (adapted from Stevens et al. 2020). All springs can include more than one type, and all springs types can be perennial or ephemeral. Also, humans can create or modify spring type.

1	Groundwater expression of flow is subterranean, emerging within a cave (a water passage, often through limestone or basalt), before emerging into the atmosphere or subaqueously into a surface pool or channel. Lentic (standing or slow-moving) and/or lotic (fast-moving) flow conditions can exist.	Cave Spring
	Groundwater expression of flow emerges or emerged in a subaerial setting (in direct contact with the atmosphere), including within a sandstone alcove or subaqueously (beneath a body of water), but not from within a cave. Lentic and/or lotic flow conditions can exist.	2
2	Groundwater is not expressed at the time of visit (the springs ecosystem is not flowing; the soil may be dry or moist, but not saturated).	3
	Groundwater is expressed at the time of visit; saturation, seepage, and/or flow are actively expressed (water and/or saturated soil are evident); Lentic and/or lotic flow conditions can exist.	5
3	Evidence of prehistoric groundwater presence and/or flow exists (e.g., paleotravertine, paleosols, fossil springs-dependent species, etc.), but no evidence of contemporary flow or aquatic, wetland, or riparian vegetation.	Paleospring
	Not as above.	4
4	Soil is dry or moist but is not saturated by groundwater. Groundwater is expressed solely through wetland or obligate riparian vegetation.	Hypocrene Spring
	Groundwater is expressed through saturated soil, or as standing or flowing water. Lentic and/or lotic flow conditions can exist.	5
5	Groundwater is expressed, but discharge is primarily lentic (standing or slow-moving), and flow downstream from the springs ecosystem may be absent or very limited..	6
	Groundwater is expressed; discharge is primarily lotic (fast-moving) and flows actively within and/or downstream, away from the springs ecosystem.	11
6	Groundwater is expressed as a patch of shallow standing water or saturated fine sediment or soil, usually strongly dominated by hydric soils and emergent herbaceous wetland vegetation, but sometimes can include woodland or forest vegetation (e.g., palm oases, swamp forests). The slope is usually low (<16°). These sites are colloquially called wet meadows or ciénegas and include some GDE fens. Lotic flow conditions prevail.	7
	Subaqueous flow creates an open, lentic body of water, typically more than a few square meters in area, not dominated by emergent wetland vegetation, and with or without outflow.	8
7	A wet meadow with seepage emerging from the margin of an active surface flow-dominated channel or floodplain, and subject to regular flood scour by the stream channel into which it feeds.	Helocrene Spring; secondarily Rheocrene
	A wet meadow with seepage emerging outside and away from an active surface flow-dominated channel or floodplain, and not subject to regular flood scour by a stream.	Helocrene Spring
8	The groundwater table surface is exposed as a pool with standing water, without a focused inflow source, and with no outflow. Lotic flow conditions exist. Many prairie pothole springs are classified as this springs type.	Exposure Spring
	A pool is formed by one or more focused, usually subaqueous, inflow sources; generally with outflow, if not frozen.	9

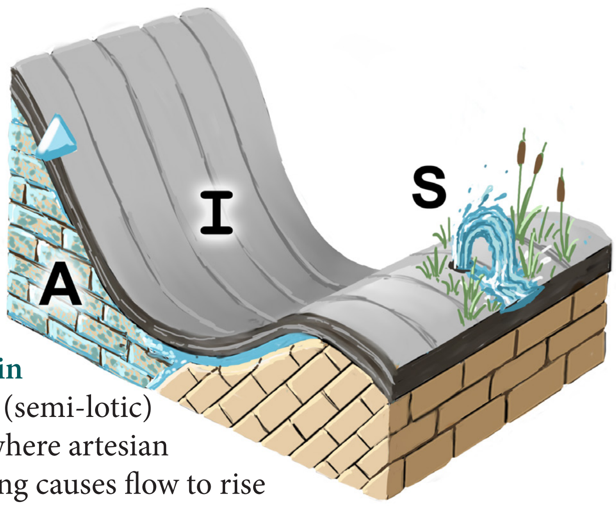
9	Springs source is surrounded by, and has contributed to the formation of, a mound composed of chemical precipitate (e.g., travertine), ice, or organic matter. Both lentic and lotic flow conditions can occur.	10
	Springs source forms an open pool which is not surrounded by a springs-created mineral, ice, or organic mound; often with a focused outflow channel. Lentic flow conditions prevail, but lotic flow may occur in the outflow channel.	Limnocrene Spring
10	Springs source is surrounded by, and/or emerges from a mound composed of carbonate (including travertine) or other chemical precipitate. Both lentic and lotic flow conditions can occur.	Mound-form Spring (Carbonate)
	Springs source is surrounded by, and/or emerges from a mound composed of ice in an ice-dominated landscape. Flow may be seasonal, and both lentic and lotic flow conditions can occur. Also colloquially called pingos or aufeis springs.	Mound-form Spring (Ice)
	Springs source is surrounded by, and/or emerges from a mound composed of organic matter, such as decomposing vegetation or peat. Lentic flow conditions generally prevail. Some GDE fens are classified as this springs type.	Mound-form Spring (Organic)
11	Springs flow emerges explosively and periodically, either by geothermally-derived or gas-derived pressure. Lotic flow conditions generally prevail. This springs type includes geothermal geysers and "coke-bottle" (CO^2 gas-driven) geysers.	Geyser
	Springs flow emerges non-explosively, but by the action of gravity.	12
12	Artesian flow emerges from one or more focused points and rises 10 cm or more above ground level due to gravity-driven head pressure. After the flow falls to the ground, lentic or lotic flow conditions may prevail. Colloquially called artesian springs.	Fountain
	Springs flow may emerge from a focused point, but without substantial artesian rise above ground level.	13
13	Springs flow emerges from a bedrock cliff and not within an established surface flow channel (although a surface flow channel may exist on top of the cliff, directly above the source).	14
	Not as above.	15
14	Focused lotic flow emerges from a bedrock cliff and immediately cascades, usually as a madicolous sheet of whitewater flow, down the cliff face.	Gushet
	Flow emerges along a horizontal geologic contact, typically dripping along a seepage front and often creating a wet backwall. This springs type includes unvegetated or vegetated seepage patches on near-vertical or overhung bedrock walls. Both lentic and lotic flow conditions can occur.	Hanging Garden
15	Flow emerges from a surface flow-dominated channel bed. Upstream of the spring source, the channel may be a perennial stream or it may be dry. Lotic flow conditions generally prevail. These springs are subject to channel flood scour.	Rheocrene Spring
	Flow emerges from a non-bedrock dominated slope that does not have a surface flow channel upslope of the springs source. Sources may emerge within an upland habitat or a floodplain, but not within the bed of a surface flow channel. In some cases, these springs may emerge from the base of a cliff, but not from the cliff itself. Lotic flow conditions generally prevail.	16
16	Flow emerges from a 16-60° slope in an uplands habitat, not associated with a floodplain or channel that is subject to regular surface flow stream flood scouring.	Hillslope Spring
	Flow emerges from the bank or terrace of an active riparian channel or floodplain and the source is subject to regular flood scour by the stream into which it feeds.	Hillslope Spring; secondarily Rheocrene



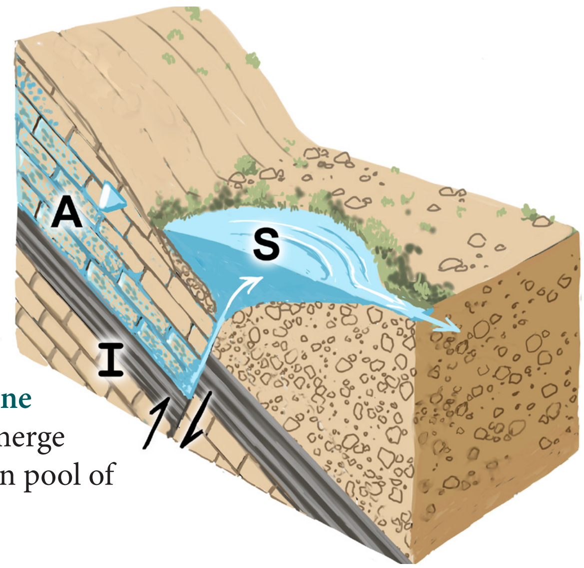
Exposure
springs occur where a water table is exposed, without flowing, at the Earth's surface.



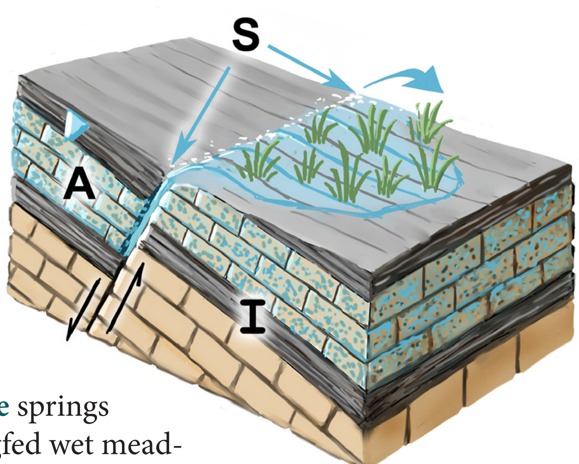
Hypocrene
springs occur where groundwater is not expressed at the Earth's surface, but shallow groundwater is discharged by transpiration through wetland vegetation.



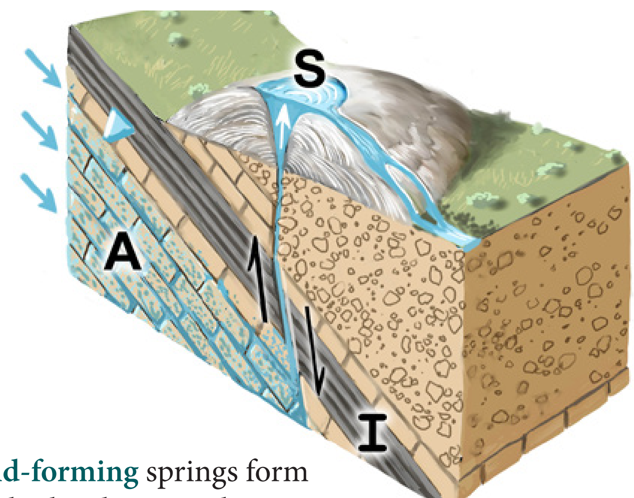
Fountain
springs (semi-lotic) occur where artesian upwelling causes flow to rise higher than the surrounding landscape.



Limnocrene
springs emerge into a open pool of water.

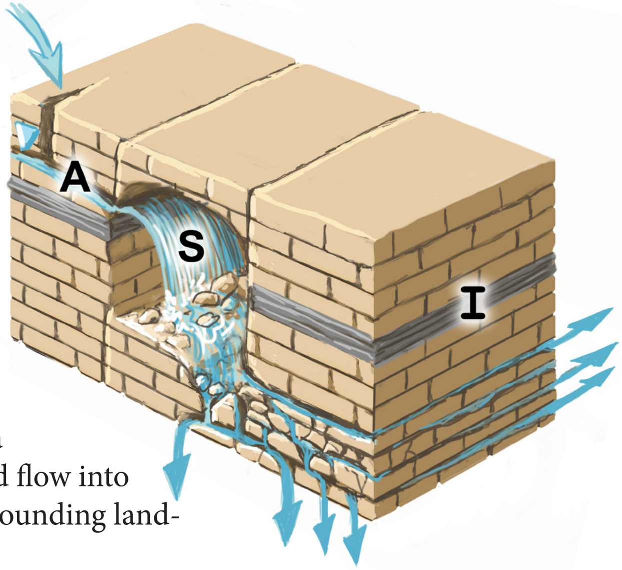


Helocrene springs are springfed wet meadows, called ciénegas at elevations up to about 2,135 m (7,000 ft), or groundwater-dependent fens at higher elevations.

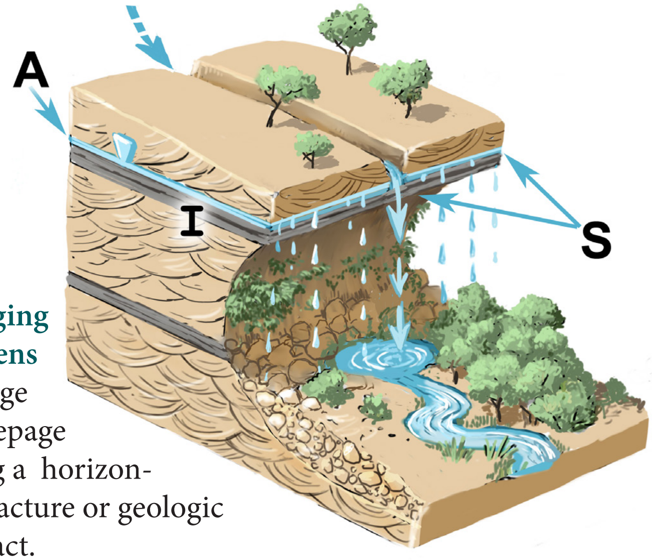


Mound-forming springs form where high calcium carbonate concentrations create travertine. This type also forms in the arctic where ice builds up, forming pingo ice hills or aufeis ice sheets.

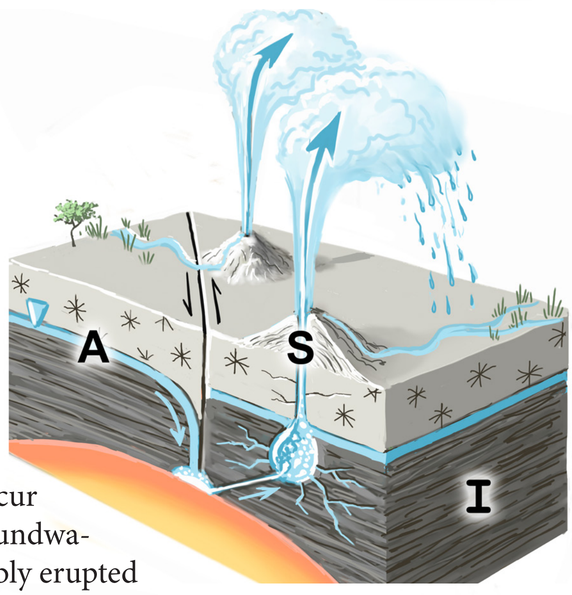
Fig. 6. Lentic and semi-lotic springs types, redrawn for SSI by V. Leshyk, modified from Springer and Stevens (2009). A=aquifer; I= impenetrable stratum; S= spring source. Images copyright, Springs Stewardship Institute.



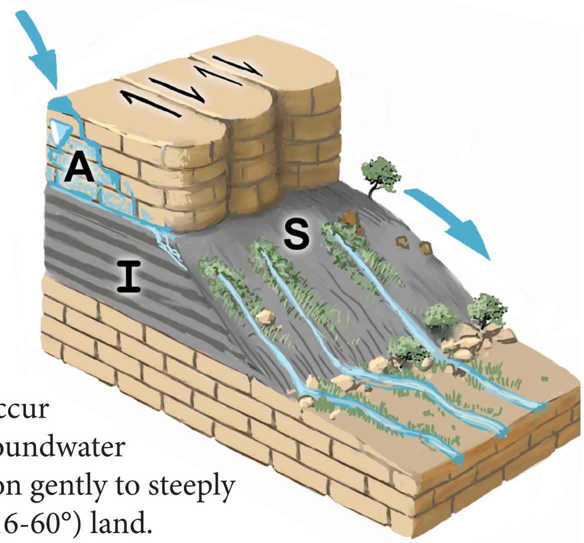
Cave springs emerge within a cave and flow into the surrounding land-scape.



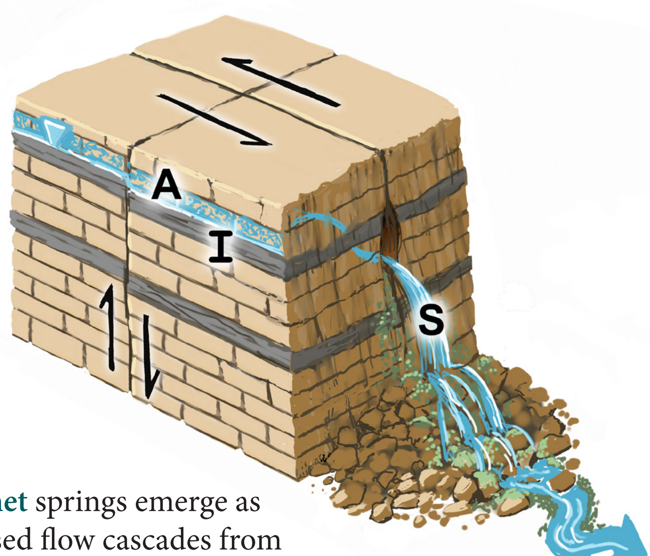
Hanging gardens emerge as seepage along a horizon-tal fracture or geologic contact.



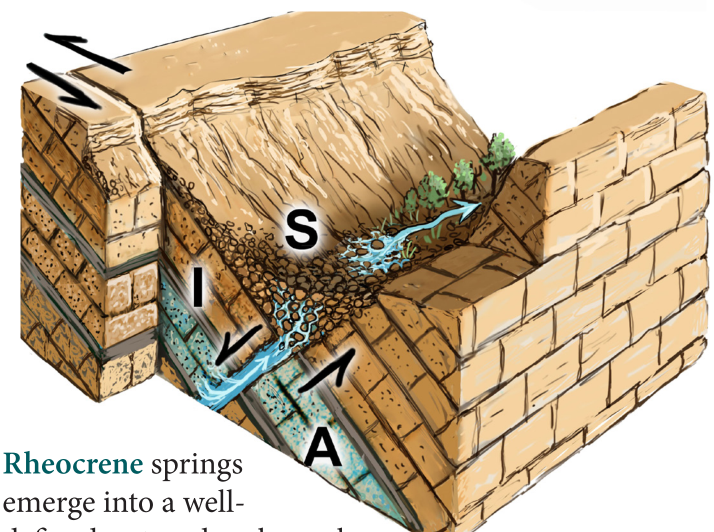
Geyser springs occur where groundwa-ter is forcibly erupted by steam or gas pressure.



Hillslope springs occur where groundwater emerges on gently to steeply sloping (16-60°) 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. 7. Lotic springs types, redrawn for SSI by V. Leshyk, modified from Springer and Stevens (2009). A=aquifer; I= impenetrable stratum; S= spring source. Images copyright, Springs Stewardship Institute.

Springs Stewardship Program

Program Design

Springs stewardship is most effective when based on a scientific approach, incorporating the following steps:

- Development of an effective administrative context.
- Definition of clear, unambiguous goals and objectives.
- Assembly of existing information and identification of needed information.
- Development and implementation of a data collection plan.
- Development and implementation of a data management and analysis plan.
- Comprehensive and systematic inventory.
- Ecological assessment based on the results of the inventory.
- Prioritization of management needs and actions based on the ecological assessment.
- Implementation of management actions.
- Monitoring as a scientific exercise with forethought, data collection, review of results, and feedback into future management actions.
- Communication and coordination with stakeholders.
- Consideration of contingencies and unexpected events.

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 help meet the needs of multiple stakeholders.

In this document, we present an integrated springs inventory protocol to provide rapid, reliable, and readily understood information on springs ecosystem components, processes, threats, and management options. These inventory and monitoring protocols have been developed over the past 20 years from conversations with many natural resource specialists and managers, and have been tested on more than 2,000 springs of different types in different geomorphic and climate settings in North America. This protocol leads springs inventory staff through several of the steps outlined above, from the iterative planning process of defining management and research goals and objectives, compiling background information, creating data collection and data management plans, and deciding which springs to survey; through springs inventory data collection and the use of those data to assess site ecological integrity; and finally to information management, reporting, and incorporation of results into improved stewardship.

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). In a structured resource management strategy, systematic inventory precedes and informs assessment, management planning, action implementation, and monitoring. Efficient, interdisciplinary inventory protocols also are essential for improving understanding of springs ecosystem ecology, distribution, status, and conservation.

Because springs ecosystems are rarely managed as such, they are frequently grouped with other ecosystem types for the purpose of regulation, management, and inventory and monitoring. A variety of governmental and nongovernmental groups play roles in protecting and managing groundwater and surface water quality, wetland and riparian ecosystem health, and other natural and social aquatic and wetland ecosystem functions. However, springs have little direct protection (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, Cantonati et al., 2020, Stevens et al., 2021).

Inventory and management techniques designed for other landforms such as wetlands or riparian ecosystems are often unsuitable for springs. For example, federal wetland delineation concepts and techniques may be considered, but are inappropriate for many springs types including naturally ephemeral springs, hot springs, hanging gardens, and other springs in bedrock-dominated landscapes. Protocols for stream-riparian hydrogeomorphic inventory may be useful for some rheocrene springs, but often are inappropriate for other springs types 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 very different roles in spring ecosystems (Springer et al. 2015). Misapplication of stream-riparian and wetlands inventory techniques can distort interpretation of springs ecological integrity (Stevens et al. 2006).

Several spring-specific inventory protocols have been developed for certain regions, individual states, or individual agencies. Some examples are the 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). These protocols provide useful insights but may not be broadly applicable to all springs.

SSI developed the Springs Inventory Protocols based on our experiences inventorying more than 2,000 springs, primarily in western North America, including the Great Basin, the Colorado Plateau (Springer et al. 2006), southern Alberta (Springer et al. 2015), and northern Mexico, as well as in Florida, Pennsylvania, and Wisconsin.. 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. Forest Service (2012), and individual researchers.

The SSI Springs Inventory Protocol is an efficient, interdisciplinary inventory protocol that is applicable to all types of terrestrial springs—subaerial or subaqueous, in any biome, and across watershed, state, and national-international boundaries. It can be used at any landscape scale of inquiry, from that within a single spring ecosystem, to springs inventory on a regional, continental, or global basis, and can be used for basic monitoring to quantify ecosystem changes over time. The protocol described here provides a quantitative foundation for understanding the physical, natural, cultural, and anthropogenic influences affecting spring ecosystem function and stewardship options. It contributes to the development of springs ecosystem ecology as a field of research, and also to the advancement of large-scale spring stewardship.

Three Levels of Inventory

The Springs Stewardship Institute (SSI) springs inventory and monitoring protocols were designed to be cost-effective, rapid, and comprehensive. We define three levels of inventory:

Level 1 Inventory is a rapid reconnaissance survey of springs within a landscape or land management unit, consisting of brief visits by 1-2 staff for the purpose of georeferencing, clarifying access, and determining sampling equipment needs (field form in Appendix A).

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

Level 3 Inventory involves monitoring of springs or springs-dependent taxa selected for long-term studies, and may include measurement of variables used in Level 2 inventories, as well as other relevant variables.

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. Testing and refining these inventory protocols are ongoing, and we welcome suggestions for improving them.

Assessment

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. While this assessment may be completed following any springs inventory, it is explicitly built into the Level 2 Inventory protocol, and described in the Level 2 Inventory section of this document.

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 support reporting and analyses. Few such information management systems presently exist for spring ecosystem data. Often, existing springs data are 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 (https://springsdata.org/; Fig. 8). This database is relational, providing the ability to contain many surveys for each site and to analyze diverse variables and trends over time. It is broadly framed to accommodate a wide array of information types.

SSI developed Springs Online based on the assumption that the springs steward(s) will want, use, and maintain a long-term information management program for their springs. In the case of large landscape management units (e.g., National Parks, National Forests, and Tribal reservations), such an information management system needs to relate to the steward's goals. Spring stewards need data archival access to site photography, specimen data, and clearly defined metadata and standardized reporting. Springs Online supplies these information needs by providing a secure, user-friendly interface for data entry and analysis. For example, the fields in the database have dropdown boxes and are aligned with the field sheets to ease the data entry process.

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. Each night all data are exported into a geodatabase that SSI can package and deliver to land managers. 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

Fig. 8. Springs Online at https://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.

offers secure archival of such information. Administrators 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 efforts may be extended to the general public, private landowners, Tribes, local, state, federal, and international agencies, and NGOs, and can provide the transition from awareness to engaged action. Private landowners 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 Springs Online, and related to a spring or a particular survey.

Volunteer citizen scientists may assist with springs inventory and ecological assessment, 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.

Background Information

Overview

Once the administrative context and focal questions of the program have been established, spring stewards should develop a synopsis of background information on their springs. The type of background information described below is important for any land manager interested in managing springs as ecosystems and components of the watershed. It will complement the data gathered during on-the-ground inventories, and can also be useful for prioritizing springs for field study, and aid in developing stewardship plans. It 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, including site protections; 3) regional ecology and biodiversity, particularly of sensitive species; 5) prehistoric and historic uses; and 6) stakeholder issues. 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 springs stewards should compile it into a concise, well-referenced, archived format, so that present and future stewards will have a clear understanding of the rationale and history of management decisions. As is the case with field data, the management of background information is as important as its collection. In particular, stewards should be sure to incorporate bibliographic information into their data management plan.

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. Groundwater 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 one step 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, as 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 field work. 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.

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 multiple 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 providing 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; Cuthbert and Ashley 2014; Fig. 9). 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 over 12,000 years, requiring stewardship planning that includes human impacts (West and McGuire 2002, Kodric-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 also to complete the administrative context section 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.

Fig. 9. Springs often have a lengthy, but sometimes obscure history of use. Bennett Spring in Northern Arizona.

Field Work Planning

Site Selection

To be informative and useful to stewards, springs inventories in large landscapes must address stakeholder information needs. Most stewards have questions about specific, high priority springs while still wanting some general information about the dozens or hundreds of smaller springs within the management area. In order to effectively answer both the specific and general questions (especially within a limited budget) it is necessary to carefully consider the sampling strategy.

The inventory sampling strategy should be based on the steward's questions regarding the springs under their jurisdiction. For example, in order to answer any questions concerning the status of springs across the landscape (as opposed to a question about a specific spring) it is necessary to survey every spring or else use a statistically rigorous sampling strategy-- this includes some level of randomness in the selection of springs to survey and an adequately large sample size.

If there are questions about the general distribution or status of springs across the landscape, or if the land manager wants to construct a groundwater model, a Level I inventory of springs across the entire landscape is a useful starting point. Level 1 distribution data can then be used to randomly select a suite of springs for Level 2 inventories; this provides a statistically rigorous way to answer specific question about the ecological integrity of the springs. A stratified-random sampling design can also be useful. The site selection can be stratified by location, elevation, and/ or springs type, to help ensure full representation of springs across the land management unit with a slightly smaller sample size. Springs are often spatially clustered, and springs within clusters are likely to be similar. Statistical cluster analysis can be used 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 the selected clusters. It can also be advantageous to stratify the sampling design according to springs type to ensure sampling of rare springs types. Alternatively, a pure random study design can be used with a large enough sample size to be sure rare springs types are represented. Depending on the specific question posed by the land manager, power analysis can be used to estimate the appropriate sample size needed to answer the land manager's question with statistical rigor. 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 if the overarching question is about the average condition of all springs on the landscape.

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 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.

Permits

Prior to field data collection, state, federal, Tribal research permits, or permission from private landowners, may be required. 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 the survey crew intends to collect specimens are during inventory, it is necessary to select and communicate with a repository for the specimens. It is a good practice to collect and prepare voucher specimens for curation into professional collections; this will benefit further research, monitoring, and potential litigation.

When to Sample

There is no single ideal season to conduct spring inventories. 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 areas with seasonally varying precipitation is subject to similar arguments.

While a single site visit is highly informative, stewards should be aware that compiling complete (or nearly complete) species lists will necessarily require multiple visits to a spring, a Level 3 inventory effort. For example, GCWC (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.

Crew Organization and Training

Level 1 inventory data may be collected by an individual or a team of 2 people; a Level 1 inventory is usually completed in 10 to 15 minutes. While the data collected during a Level 1 inventory is quite limited, the crew should receive some specialized training, including use of the springs classification system, ability to recognize anthropogenic manipulations commonly done at springs (e.g., pond excavation; spring box, pipe and trough installation), and proper use of their GPS unit, including the ability to identify the spatial error, datum (e.g., NAD83 or WGS84) and different coordinate formats.

Level 2 inventory data are designed to be gathered during a 1–3-hour site visit by 4-5 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 wildlife biologist, and a botanist. One crew member serves as the crew leader and makes command-level decisions on logistics, safety, field equipment, and data management. Close coordination among team members is absolutely necessary to ensure quality, consistent data.

Coordination and training of the survey team should take place prior to the field season, including both laboratory and field activities. Beyond training in field techniques, we strongly recommend that each team member take time to practice data entry prior to joining a field crew. Each team member should do this, even those who will not ultimately be responsible for data entry; this exercise is immensely helpful to clarify the organization of these complex ecological data and the sequence of field data collection.

SSI staff regularly lead workshops to train our collaborators to conduct surveys using the Springs Inventory Protocol. These workshops consist 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 are available through the SSI website at springstewardshipinstitute.org. Quality assurance of the data within the database depends on well-organized and thorough data-entry.

Volunteer Coordination

Volunteers can provide an important work force for springs stewardship, but volunteer coordination and training are needed to ensure the credibility and proper entry of the data collected. State and federal agencies often require that volunteer services agreements and release forms be completed when volunteers work on land managed by these agencies. 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.

Logistics Planning

Following site selection, it is important to develop a schedule and route plan for the inventory team to access springs (Fig. 10). The plan should minimize travel

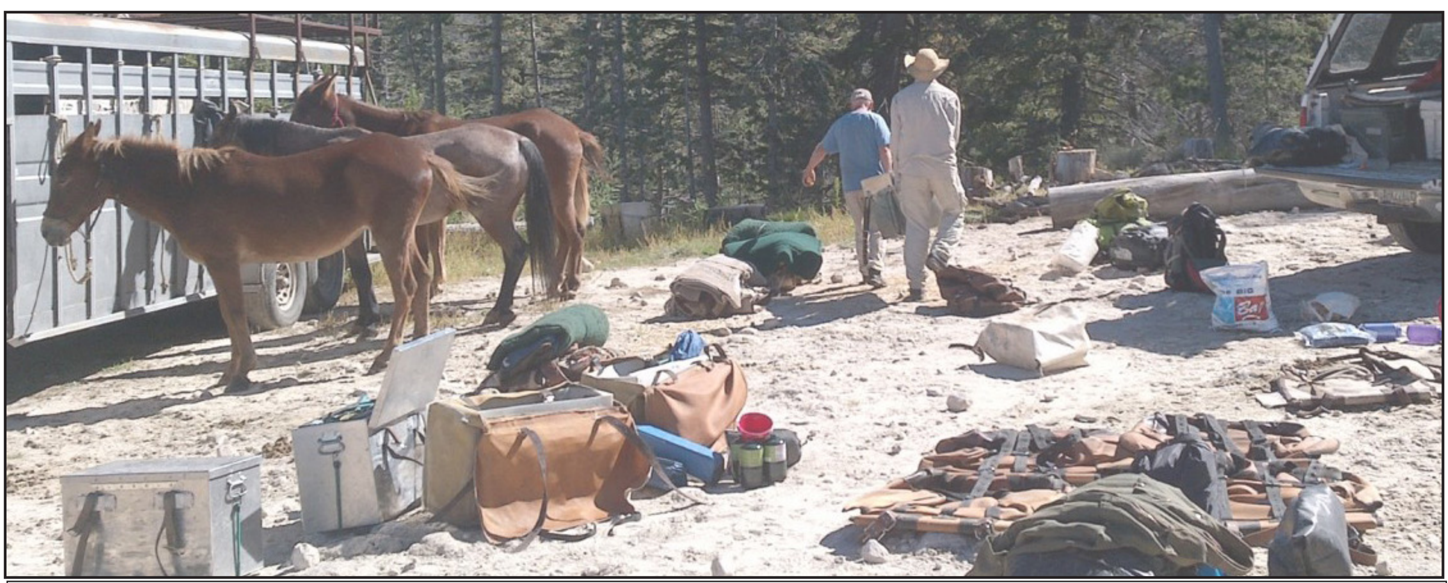


Fig. 10. Surveying springs in remote landscapes can require extensive preparation and contingency planning. In 2018, SSI surveyed springs in the Gila Wilderness, New Mexico and utilized pack mules to carry field and camping equipment.

distance and time, and also indicate 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 are frequently 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 other 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. Recording a GPS point at one's vehicle prior to beginning a remote field inventory is a practical safety measure.

Equipment List

The equipment useful for a Level 2 inventory are listed in Table 2. 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 (Fig. 11). It is nearly axiomatic that the more expensive a piece of electronic field 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 size.

Fig. 11. Much of the basic equipment needed for a Level 2 springs inventory is shown in this photo. Necessary gear that is not shown in this photo includes the Solar Pathfinder, binoculars, equipment for measuring flow, a trowel or digging knife for harvesting plant specimens, a plant press, and vials and envelopes for preserving invertebrate specimens.

Table 2. List of equipment recommended for conducting Level 2 Springs Inventories.

General and Safety Gear

Background information
- Field site location information
- Maps
- Previous survey reports
- Land access permits
- Plant checklist

Field protocols
Field sheets (print some on Rite in the Rain paper)
Clipboards
GPS units (at minimum 2) with extra batteries
Pencils
Sharpies
Stopwatch
Screwdriver, pliers, wire and duct tape
Radios with charge station and car chargers
Shovel and trowel
First aid kit, soap, hand sanitizer, toilet paper
Satellite Phone/ InReach/ SPOT for emergency communications

Geography

Clinometer
Compass
Flagging and pinflags
Metric ruler (15 or 30 cm)
Measuring tape (30 m)
Measuring tape (50 m)
Range finder (for very large sites)
Solar Pathfinder (remember legs, base, and the correct latitude disc)

Water Chemistry

Thermometer (°C) for air and water
Water chemistry probes (carry at least one back-up)
Calibration log book for water-quality meter
Calibration solutions for pH and conductivity
Distilled or deionized water (0.5 L/day)
Cups for calibration solutions
Q-tips to clean sensors
Dissolved oxygen test kit

Flow

Portable cutthroat flume and leveler
Weir plate
Pipes/ tubes for directing flow
Volumetric containers (buckets, measuring cups)
Velocity meter (for high discharge springbrooks)

Biota- All

Field guides (plants, invertebrates, vertebrates, etc.)
Binoculars
Hand lens (10x) for botany, invertebrates, geology

Botany

Plant press and newspaper
Botanist's choice of equipment for harvesting plant specimens (trowel, digging knife, etc.)

Invertebrates

For aquatic invertebrate spot sampling and collecting:
- Aquarium nets
- Ethyl alcohol (80%)
- Forceps (several)
- Glass vials
- Schmidt pinning boxes

For aquatic invertebrate quantitative sampling:
- Kicknet
- Surber sampler
- Petite Ponar dredge

For terrestrial/ flying insects:
- Aerial sweepnet
- Killing jars
- Ethyl acetate (90%)
- Insect pins, points, and glue
- Pinning boards
- Paper or wax paper envelopes

Equipment Decontamination

Scrub brush
Plastic tubs or trays (3)
Household bleach or 70% ethanol
Spray bottles
Five-gallon buckets with lids (1-2)
Extra water for rinsing gear

Field Sheets

Field data sheets are the most efficient and reliable method of information documentation for Level 1 and 2 springs inventories (Appendices A, B). Multi-staff team information compilation and detection of data entry errors is impossible without hard-copy field sheets, and springs-related data have proven to be 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, followed by Quality Assurance/Quality Control (QA/QC) procedures.

The field sheets designed by SSI and described below are designed to facilitate field data entry and follow the organization of Springs Online database. Data fields are organized 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 the field work.

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

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, or vehicular accidents. The springs under study might be submerged by a beaver dam impoundment or buried by debris flow following a flood.

Encountering New Springs

Survey crews often 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. A provisional field name should be respectful, and selected based on unique site characteristics. Avoid commonly used names, such as "Big", "Little", "Cold", "Warm", "Hot", or common plant names, such as "Cottonwood", "Willow", etc.

Inability to Locate Springs

Mapped springs locations commonly are inaccurate or blatantly incorrect. Spring sources can also move following fire, debris flow, flooding, and other disturbances. For example, rheocrene sources may migrate up- or down-channel due to groundwater fluctuation and flood-related geomorphic changes to the channel. Mapping inaccuracies, particularly in rugged terrain or heavily forested areas, may prevent the crew from finding the spring. The crew should proceed to the GPS coordinate of the mapped spring, establish a search radius, and designate a time limit for locating the spring (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 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.

Leave No Trace

Survey crews should take care to minimize impact to the springs ecosystem. The inventory team focuses their activities in 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 is the responsibility of the inventory team; the site should be left in as close to its original condition as possible. After completing a spring survey, crew members should scan the site and make sure there is no obvious evidence of their visitation. The crew should make sure no gear or trash is left onsite. The crew should rehabilitate any ground disturbance (e.g., dams constructed for flow measurements). Pin flags or flagging tape should be removed. Out of respect for the ecosystem and future visitors, surveyors should leave the site in as good condition or better than they found it.

Equipment Decontamination

Disease-causing organisms can be easily transported between wetland environments by people. Anyone working at wetland sites like springs, stock ponds, rivers, or streams should decontaminate their gear between field sites to prevent the spread of potentially damaging organisms. For example, chytrid fungus (*Batrachochytrium dendrobatidis*), which is causing widespread global amphibian population declines, can be transported on boots, clothing, and equipment (Canadian Herpetofauna Health Working Group 2017). Other nonnative micro- and macro- organisms transported by humans include ranaviruses, snake fungal disease (caused by *Ophidiomyces ophiodiicola*), sudden oak death (caused by *Phytophthora ramorum*), New Zealand mud snails, quagga mussels, and didymo (*Didymosphenia geminata*). Seeds are easily transported from place to place on clothing, shoes, and equipment. Many plants, like cheatgrass, can cause significant ecosystem disruption when they colonize a new site.

We can do our best to prevent the spread of these and other (even unknown) diseases and organisms by properly decontaminating gear. The below protocol was compiled after reviewing decontamination protocols for workers in many wetland habitats.

When to decontaminate gear: After leaving a spring, surveyors should decontaminate shoes, nets and any other items that touched water to prevent spread of disease-causing organisms. Surveyors should be especially diligent about decontaminating gear when traveling between watersheds, between tributaries of a river or stream, or when moving upstream in a watershed. When visiting several sites in a day or when it would be otherwise impractical to decontaminate between sites, consider carrying multiple sets of gear (footwear, nets, sampling equipment, etc) and rotate through clean gear throughout the day. Keep soiled gear separate from clean gear by storing it in sealed containers until decontaminated.

How to decontaminate gear: Gear should first be cleaned of mud and debris, including seeds. Then, the gear should be chemically sanitized to kill pathogens or other potentially damaging organisms. While certainly not the only options available, we recommend a 6% solution of hypochlorite (bleach) or 70% ethanol as practical decontamination solutions. Both are widely available and are broadly effective against pathogenic organisms. Drying is not recommended as a decontamination strategy, because while some organisms are killed by sunlight and drying, many are not. Quagga mussels, for instance, are able to survive up to 5 d in dry environments. Likewise, didymo requires 48 hr of dry conditions in sunlight for drying to be an effective method of decontamination.

Where to decontaminate gear: High concentrations of bleach and ethanol are harmful to aquatic organisms, so do not decontaminate gear at the field site. Leave the site and go at least 50 m from water. Store used bleach or ethanol for proper disposal.

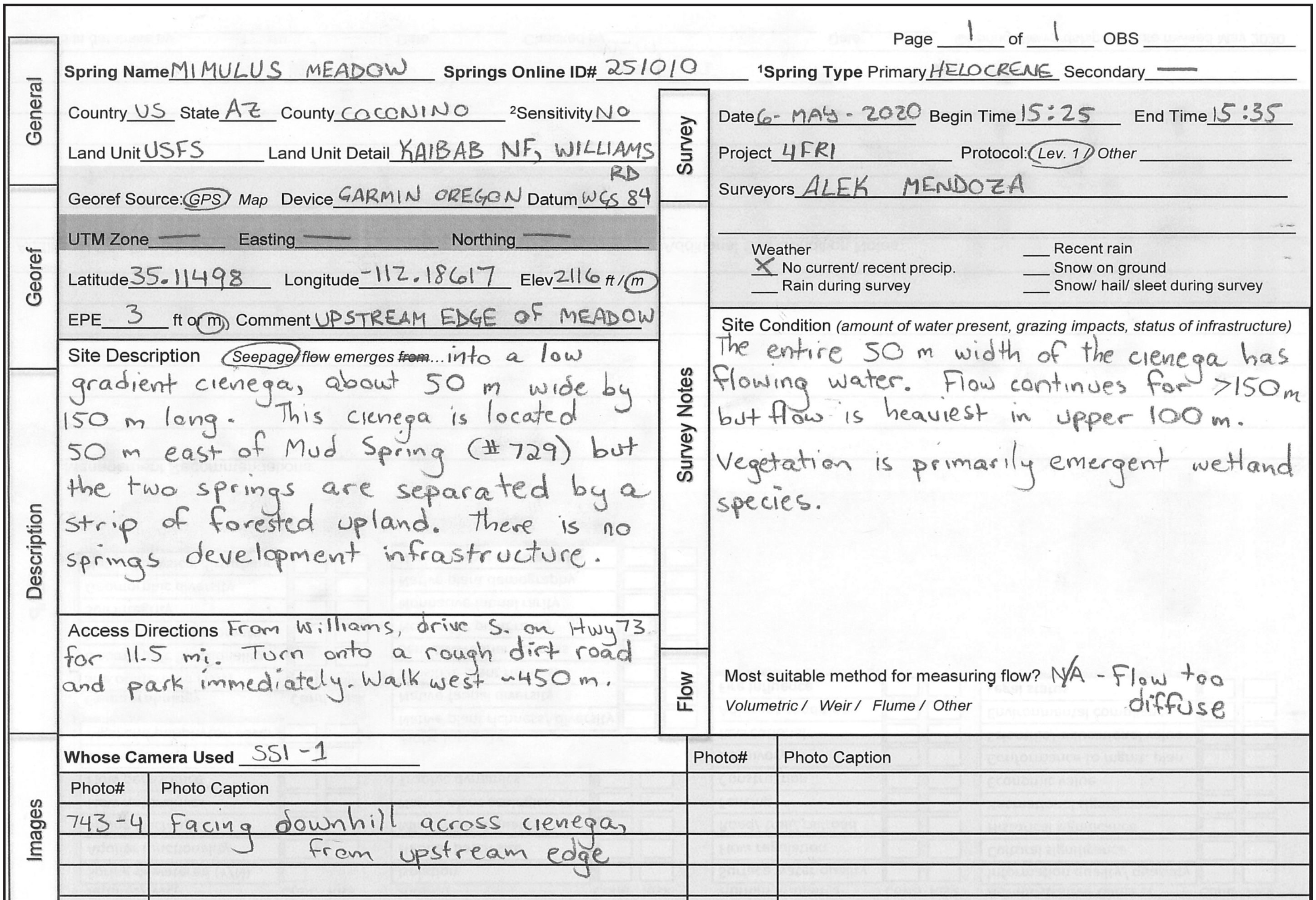
Level 1 Springs Inventory

Introduction

A Level 1 inventory of the springs across a landscape is useful for understanding the spatial distribution of springs and springs types, as well as providing practical information to help surveyors better prepare for Level 2 surveys. Given the generally poor 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 more intensive Level 2 surveys at selected springs. In large landscapes, a Level 1 inventory should be initiated by first reviewing available mapping data and conducting interviews with knowledgeable individuals about spring distribution. Such background research, completed prior to Level 1 inventory field work, will greatly reduce field search time and project costs.

Level 1 Survey Protocol

A Level 1 survey is a brief (10-20 minute) site visit during which the field crew rapidly documents a spring using a simple, standardized protocol. Level 1 surveys are used to verify reported springs locations, record newly discovered springs, record instances of reported springs that are dry or mismapped, and document what equipment and staff will be needed to conduct a Level 2 survey, if recommended (Fig. 12). Level 1 surveys are typically conducted by 1-2 trained individuals, such as technicians, scientists, or members of the educated gen-



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General

Spring Name MIMULUS MEADOW | Springs Online ID# 251010 | [1]Spring Type Primary HELOCRENE Secondary —

Country US | State AZ | County COCONINO | [2]Sensitivity NO

Land Unit USFS | Land Unit Detail KAIBAB NF, WILLIAMS RD

Georef

Georef Source: (GPS) Map | Device GARMIN OREGON | Datum WGS 84

UTM Zone — | Easting — | Northing —

Latitude 35.11498 | Longitude -112.18617 | Elev 2116 ft / (m)

EPE 3 ft or (m) | Comment UPSTREAM EDGE OF MEADOW

Description

Site Description (Seepage) flow emerges from... into a low gradient cienega, about 50 m wide by 150 m long. This cienega is located 50 m east of Mud Spring (#729) but the two springs are separated by a strip of forested upland. There is no springs development infrastructure.

Access Directions From Williams, drive S. on Hwy 73 for 11.5 mi. Turn onto a rough dirt road and park immediately. Walk west ~450 m.

Survey

Date 6-MAY-2020 | Begin Time 15:25 | End Time 15:35

Project 4FRI | Protocol: (Lev. 1) Other

Surveyors ALEK MENDOZA

Weather
X No current/ recent precip.
__ Rain during survey
__ Recent rain
__ Snow on ground
__ Snow/ hail/ sleet during survey

Survey Notes

Site Condition (amount of water present, grazing impacts, status of infrastructure) The entire 50 m width of the cienega has flowing water. Flow continues for >150 m but flow is heaviest in upper 100 m. Vegetation is primarily emergent wetland species.

Flow

Most suitable method for measuring flow? N/A - Flow too diffuse
Volumetric / Weir / Flume / Other

Images

Whose Camera Used SSI-1

Photo#	Photo Caption	Photo#	Photo Caption
743-4	Facing downhill across cienega, from upstream edge		

Fig. 12. Field sheet filled out with data for a Level 1 springs inventory. This simple survey was completed in 10 minutes. The field sheet is designed to streamline data entry into Springs Online.

eral public. The information recorded in a Level 1 survey should include:

- GPS coordinate at the spring source (include equipment type, datum, and position accuracy)
- Driving/ hiking directions and caveats about access to the site
- Observer name(s), date, and time of survey
- Written description of the spring and notes on its condition, including anthropogenic alterations and the condition of any infrastructure
- Photographs of the source and microhabitat array, with written photo log
- Spring type (Table 1, Fig. 6 and Fig. 7) and approximate springs-influenced land area
- Description of the amount of flow and the method best suited to measure spring flow rate

A Level 1 survey can be performed during programmatic searches for springs or on an ad libitum basis as springs are encountered during other activities. The Level 1 field sheet is attached as Appendix A. Alternately, surveyors may use the first page from the Level 2 field sheet packet (Appendix B) to conduct a Level 1 survey, simply leaving the microhabitat section blank.

Level 2 Springs Inventory

Introduction

A Level 2 springs inventory includes documentation of an array of variables related to site geography and geomorphology, biota, flow, and the sociocultural-economic conditions of the springs at the time of the survey. A survey crew that uses this protocol is documenting the actual conditions at the spring, rather than potential conditions—a practice needed to establish baseline conditions and for monitoring comparisons (e.g., Stevens et al. 2016). The protocols presented here were informed by discussion with many resource stewards and recommendations made by GCWC (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. 3). The variables selected are the suite needed to improve basic understanding of the spring's ecosystem ecology, ecological integrity, and anthropogenic influences such as ground and surface water extraction or pollution, livestock use, recreational visitation, and climate change.

With appropriate background information, a single Level 2 site visit is sufficient for assessment of ecosystem integrity. If thoughtfully implemented, the Level 2 inventory and information management protocols presented here also may be suitable for basic monitoring and trend assessment, and can provide baseline data for long-term Level 3 site management and restoration efforts.

Level 2 springs inventories are rapid assessments of sites. We regard more in-depth activities such as wetland delineation, soil profile analyses, paleontological and historical use investigations, and establishment of vegetation transects and plots as Level 3 research, management, and monitoring activities, discussed in a later section and outside the scope of the Level 2 inventory.

In the following sections we describe the rationale behind selection of variables considered important for Level 2 springs inventory, in addition to describing sampling methods and providing guidance on collecting and recording data on each variable. The text guides the reader through the field forms, which are attached as 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.

Sequence of Tasks

Upon Arrival

Several tasks should be completed first when conducting a Level 2 survey.

- The crew should approach the spring slowly and quietly, allowing the wildlife biologist to proceed first and observe any wildlife at the site.
- Once the full crew arrives on site, the crew should take care to place their gear in a thoughtful location some distance from the springs source. This will help keep the source area from becoming trampled.
- The crew splits up and studies the site, looking for upstream sources and considering how to best classify the geomorphic features of the site as microhabitats. They should also looks for wildlife tracks and other sign as they search the site.
- The crew comes back together and discusses what they observed. They decide as a group the extent of the springs habitat that will be included in the survey, and the number and distribution of microhabitats that they will describe and map.
- The crew leader hands out field sheets, the geographer records the start time of the survey, and each crew member begins their assigned portion of the survey.
- The hydrogeologist prioritizes measuring water quality immediately, to make sure that the water quality measurements are not affected by the crew disturbing the water near the source.

Before Departing

After the crew has finished collecting all data, the crew leader collects the data sheets, checks each for completion, and makes sure that the spring name and date are written on each. The crew leader files the field sheets into a folder labeled with the spring name.

While the crew leader is checking the data sheets, the rest of the crew carefully pack their gear and then scan the site and make sure there is no obvious evidence of their visitation. They should make sure no gear, trash, pinflags or flagging tape are left onsite, and dams constructed for the flow measurement are broken down.

Field Sheet Page 1: Site Description, Geography, and Microhabitats

Overview

A clear, concise description of the site, including its location, elevation, and microhabitats, is essential for mapping, monitoring, and relating physical elements of the springs to its biota and human uses. The first page of the Level 2 inventory field form includes general geographic and geomorphic information about the site and basic information about the survey.

This first page should be filled out by the crew geographer, in consultation with the other staff members. Most of the variables on the first page are self-explanatory. For the more technical variables, the geographer can refer to page 2 of the field sheet packet, which lists possible responses for many of the data fields. More information on each variable is presented below.

General Section

Spring Name: Many springs are unnamed, and sometimes the name on topographic maps conflicts with that used by the land managing agency. Typically, it is best to use the name assigned by the land manager. In cases where no spring name exists, it is helpful if the inventory team gives the spring 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 often appropriate. To reduce 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 in the latter case may be impermanent because vegetation changes through time.

At large springs complexes that have several distinct sources, it is sometimes appropriate to assign a name to each spring source in the cluster. In these cases, names should be considered carefully, and georeferencing and mapping should be done carefully as well. We recommend the use of descriptive names that will help future survey crews relocate each source without confusion. For example, for a complex of three springs, the names Basalt Spring North, Basalt Spring Center, and Basalt Spring South will be much more helpful to future survey crews than the names Basalt Spring A, Basalt Spring B, and Basalt Spring C.

It is customary in the United States to forgo the use of apostrophes in geographic names. The U.S. Geological Survey governs the naming of geologic features in the United States. A provisional name applied by the inventory team may eventually become the official name for that springs ecosystem. Therefore, it is important to assign a respectful name.

Springs Online ID: A numeric Site ID is automatically generated when a spring is added to the Springs Online database. It is a useful identifier, particularly for springs with commonly used names, such as "Big Spring."

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; updated in Stevens et al 2020) identified 12 types of springs that include lentic (standing water) and lotic (moving water) springs. Use the dichotomous key (Table 1) and drawings (Fig. 6 and Fig. 7) to properly identify the springs type. The list of springs types is also printed on Page 2 of the field sheet packet. It is sometimes appropriate to designate a primary and a secondary springs type. If elements of two or more springs types are present at a site, we assign the primary springs type based on the attributes of the upstream-most source, and the secondary springs type based on attributes of sources emerging farther downstream. Alternately, the geographer may prefer to assign the primary springs type based on the attributes of the site that are the most dominant.

Location and Ownership: Country, state, county, land unit (e.g., US Forest Service, NPS, or Private), and land unit detail (e.g., Coconino National Forest, Mormon Lake Ranger District) are required fields in the Springs Online database. These fields are also important for understanding the management context of the spring and also for assigning database permissions so that data on the spring will be made available to the appropriate users of Springs Online.

Sensitivity: 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 restrict access to sensitive information, as the steward wishes.

Georeferencing Section

Georef Source and Device: The source used for georeferencing (GPS, map, etc.) indicates the precision of the location information. The type of device (for example, Garmin eTrex or Trimble) can also indicate the precision of the data. Keep in mind that steep canyons may result in a high GPS error (noted in EPE, below).

The GPS coordinate should be recorded as close to the spring source as possible (Fig. 13).

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; failure to do so may result in positioning error of hundreds of meters.

Geographic Coordinates: Springs Online currently accepts geographic coordinates in decimal degree or UTM formats. Therefore, we recommend that one of these two formats be used to record the coordinate in the field. If using UTM, be sure to include the zone.

Elevation: Accurate elevation data are essential for groundwater modeling; however, accurate elevations are notoriously difficult to obtain using GPS. Therefore, we recommend confirming the GPS elevation reading with a topographic map or digital elevation model. Be sure to note the units (m or ft), as readings will need to be converted to meters when entered into the Springs Online database.

EPE: This stands for estimated position error. On some GPS units, this information will be found in a field called "GPS Accuracy." Be sure to note the units (m or ft), as readings will need to be converted to meters when entered into the Springs Online database. The geographer can have a higher confidence in the accuracy of GPS locations with a lower estimated position error (EPE).

Comment: Use this field for any concerns or notes about the GPS coordinate (e.g., if the source is under an overhang and the coordinate was recorded 30 m away where a GPS signal could be obtained). If the GPS coordinate is a correction of previously documented coordinate for the spring, note the distance and direction of the correction.

Fig. 13. The GPS coordinate should be recorded as close to the springs source as is feasible. Hydrologist Abe Springer recordings the GPS coordinate on top of the mineral mound formed by a hot spring in La Plata County, Colorado.

Description Section

Site Description: In this field, the geographer should describe the permanent or long-term geomorphic context and landscape setting of the site. Typically, this description should apply to the permanent or semi-permanent features of the site; focus on aspects of the site that are unlikely to change. Springs type is recorded elsewhere, but in this field, it is appropriate to supply detail about the flow path in relation to geomorphic features. We find that beginning a site description with the phrase "Seepage emerges from..." or "Flow emerges from..." is a helpful practice. The geographer might also describe evidence of historical use, including any long-present infrastructure such as fences, pipes, wells, and springboxes. This is a free text field in the Springs Online database, allowing space for describing the site, but not its ecological condition (see Site Condition, below).

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 if it requires a difficult climb, this information is important to record. Further, if a site is only accessible by hiking a long distance or by crossing private land with large dogs, documenting these obstacles will expedite future inventory and monitoring efforts. Special attention should be paid to documenting driving directions on US Forest Service lands; road access and road numbers on the ground often differ drastically from the information available on GPS units, the internet, and even US Forest Service road maps. Surveyors who take careful notes on road numbers, driving distances, and the direction of each turn, will save future surveyors much time and frustration.

Survey Section

Survey Date, Begin Time, and End Time: The survey date is a required field. The beginning and ending times provide documentation of the total time spent conducting the survey, which is helpful for interpreting faunal data. The ending time is easily forgotten: all crew members should remind the crew leader to record the time at the end of the survey.

Project: This is a required field in the Springs Online database, and refers to collection of surveys. Projects are easy to create and facilitate organized data entry, QA/QC, and reporting. We often group surveys into projects based on a single trip to the field (e.g., Cibola NF June 2020) or funding source (NV State 2021) for convenience when reporting. Projects may easily be combined later.

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

Weather: Record whether or not there has been recent precipitation. The recent addition of rain or snow to a landscape can affect spring flow rates, soil moisture, water chemistry, and even the surveyors' ability to distinguish a spring from a pothole full of rainwater or snowmelt.

Site Condition: In this free text field, the geographer should describe the condition of the springs at the time of the survey. Information recorded in this field is temporal, as opposed to the site description information (above). Think about aspects of the site that one might expect to be different next month or next year. This might include evidence of recent flooding or fire, current evidence of grazing, or evidence of recent recreational use. While the presence of springs development infrastructure like pipes and tanks will be included in the site description (above), the current status of the infrastructure should be described in site condition (e.g., the fence is down in three places and the springbox has 1 cm of water in it.) While surveyors conducting a Level 2 survey will usually measure the springs flow rate, it is informative to also include a verbal qualitative description of the amount of water present in the site condition section. For example: "the spring is dry," or "there is 1 meter of standing water in the excavated tank" are examples of important information that may not be clearly communicated from a spring flow measurement

Microhabitat Section

Springs are complex ecosystems, in part because they can include a suite of geomorphically distinctive microhabitats. Geomorphic microhabitats are physical landform components of the springs ecosystem that develop from a variety of physical processes and are subject to distinct environmental forces. Pools, springbrook channels, hyporheic zones, wet or dry bedrock walls, madicolous zones (shallow sheets of racing whitewater), and other microhabitat types can occur in close proximity, but may support entirely different assemblages of organisms, which may or may not interact with each other, but contribute to the diversity of life at springs.

Microhabitats are at the center of the Springs Ecosystem Conceptual Model (Fig. 3). The microhabitat array at any springs ecosystem is determined by the geomorphology of the site, and in turn influences plant species occurrence, species richness, and microclimate. Microhabitat diversity at springs has ecological consequences for springs ecosystems. After accounting for expected species-area effects, microhabitat diversity positively correlates with vascular plant richness and land gastropod diversity in western North America and elsewhere (Springer et al. 2015, Ledbetter et al. 2016, Sinclair 2018). Thus, the area of the springs-influenced habitat and the microhabitat heterogeneity of the ecosystem are important secondary variables to consider in springs inventory and management.

A simple and direct way to evaluate microhabitat heterogeneity at a springs ecosystem is to use metrics designed to assess species diversity, which take into account the number of species as well as "evenness," or abundance of each species relative to the others. The Springs Online database calculates geomorphic diversity using the Shannon Diversity Index. Rather than using species number and relative abundance, the geomorphic diversity calculation is based on the number and relative size of the different microhabitats.

Microhabitat Name and Description: Upon arrival at a spring, the team should discuss and agree upon the array of geomorphic microhabitats existing at the site. This is done first, because the site map and vegetation description are based on this information. Surveyors should define microhabitats based on site geomorphic features, rather than vegetation. While patches of vegetation will sometimes correspond with geomorphic microhabitats, this is not always the case. It is also common for vegetation types to extend across more than one microhabitat.

Some sites will only contain one or two microhabitats, while large, complex sites may contain many. On the Page 1 field sheet, there is space to describe up to five microhabitats (A-E) but surveyors should always carry spare field sheets so that they may properly describe sites that have more than this. In addition to the letter identifiers, the survey crew should assign a unique name to each microhabitat that all can easily remember. For example, there could be a wet channel (A), dry channel (B), west terrace (C), and east terrace (D). These names will generally include the surface type of the microhabitat along with appropriate modifiers if necessary. For example, "channel" is the surface type for both "wet channel" and "dry channel."

After agreeing upon and naming the array of microhabitats at the spring site, the geographer characterizes each microhabitat using the following variables, which appear in the microhabitat section of the field sheet.

Area: This field is often filled in after the sketchmap is completed. The crew member responsible for developing the sketchmap should calculate the area of each microhabitat in square meters. To aid in drawing the sketchmap and calculating microhabitat area, surveyors should lay out a metric tape along the long axis of the springs ecosystem (Fig. 14). For exceptionally large sites, the geographer can use a rangefinder to determine site dimensions or walk the perimeter carrying a GPS unit.

Surface Type and Subtype: The microhabitat surface types currently accepted by Springs Online are listed across the top of Table 3. One- to three-letter codes corresponding to the surface types are listed on Page 2 of the field sheet packet.

Fig. 14. To aid in mapping and describing micohabitats, the survey crew should stretch a metric tape along the long axis of the site. A second perpedicular tape can be helpful.

Table 3. Probability of occurrence (low, medium, or high) of different microhabitat surface types at each springs type. The total number of microhabitat surface types considered likely to occur (high probability), possible (medium probability), and unlikely to occur (low probability) at each spring type are presented on the right side of the table.

	Microhabitat Type												
Spring Type	**Backwall or sloping bedrock**	**Cave**	**Channel (wet)**	**Colluvial slope**	**Mound**	**Pool**	**Terrace**	**Pool margin**	**Low gradient ciénega**	**High gradient ciénega**	**Likely Occurrence (High)**	**Possible occurrence (Med)**	**Unlikely occurrence (Low)**
Cave	High	High	High	Low	Low	Med	Med	Med	Low	Low	3	3	4
Exposure	Med	Low	Low	Med	Low	High	Low	High	Low	Low	2	2	6
Fountain	Low	Low	Med	Med	Med	High	Med	Low	Med	Low	1	5	4
Gushet	High	Med	High	Med	Low	Med	High	Med	Low	Med	3	5	2
Geyser	High	Low	Med	Low	High	Med	Med	Low	Low	Low	2	3	5
Hanging garden	High	Low	High	High	Low	High	High	High	Low	Low	6	0	4
Helocrene	Low	Low	Med	Low	Med	Med	Med	Med	High	High	2	5	3
Hillsope-rheocrene	Med	Low	High	Med	Low	Med	High	Low	Med	Med	2	5	3
Hillsope-upland	Med	Low	High	Med	Low	Med	High	Low	Med	Med	2	5	3
Hypocrene *	Med	Low	Low	Med	Med	Low	Med	High	High	Med	2	5	3
Limnocrene	Med	Low	Med	Low	Med	High	Med	High	Med	Low	2	5	3
Mound-form	High	Low	Med	Med	High	Med	Med	High	Med	Med	3	6	1
Rheocrene	Med	Low	High	Med	Low	Med	High	Low	Med	Low	2	4	4

The geographer may designate a surface subtype for surface types; these are also listed on Page 2 of the field sheets. For channels. subtypes are riffle, run, margin, or ephemeral. For colluvial slope, sloping bedrock, backwall, and pool surface types, surveyors may designate wet or dry subtypes. Terraces may be assigned any of these subtypes:

- Hydro-riparian zone (HRZ), flooded more than once per year
- Lower riparian zone (LRZ), flooded every 1-2 years
- Middle riparian zone (MRZ), flooded every 2-10 years
- Upper riparian zone (URZ), flooded less often than once per decade

The geographer may also combine these subtypes; for example, MRZURZ would correspond to a terrace microhabitat where the lower portion is flooded every 2-10 years and the upper portion is flooded less often than every 10 years.

All surface types can have an anthropogenic subtype. This designation should be used when the microhabitat was created or highly modified by anthropogenic activity. For example, an excavated pond would be assigned a "pool" surface type, and "anthropogenic" subtype.

Slope Variability: This is assessed as low, medium or high based on the uniformity of the slope within a microhabitat (e.g., a vertical wall would have low slope variability if the entire surface is consistently 90°).

Aspect: Record the average aspect of each microhabitat, as measured using a compass. To determine the aspect of a microhabitat, first determine the "fall line" of the microhabitat (i.e., in which direction does the microhabitat dip with the steepest slope). Record the compass direction of that fall line, facing downslope, in degrees. For example, the fall line for a channel microhabitat will generally be facing directly downstream, while the fall line for a stream bank microhabitat will often lead from the top of the bank down to the channel.

Using a Brunton or sighting compass will produce the most precise results. Note whether the compass has been adjusted for declination by circling True or Mag on the field sheet. Circle "Mag" (for magnetic) if the compass declination is set to 0°; otherwise, circle "True" and record the compass declination setting. If a compass declination of 0° is used (i.e., the compass is reading magnetic north), the Springs Online database converts aspect readings from the magnetic base to a true north base.

If a microhabitat is perfectly level (with a slope of 0°), then it does not have an aspect. When this is the case, aspect should be left blank. Do not write 0 in the aspect field when the microhabitat lacks an aspect; remember that with aspect, 0° = 360° = north.

Slope Degrees: Measure the slope angle of each microhabitat in degrees using a clinometer. Please note that if the slope of a microhabitat is 0 degrees, this indicates that the microhabitat is level and lacks an aspect, and thus the aspect should be left blank.

Soil Moisture: This field is an estimate of the average moisture level in the surface soil within each microhabitat on a 0-10 scale, ranging from: dry (0 = no soil moisture, soil easily separates), moist (3 = little soil moisture), wet (6 = soil easily sticks together), saturated (8 = soil is completely wet, added water does not soak up, but little or no standing water), and inundated (10 = water standing or flowing over 100% of soil surface). These categories are described in more detail on Page 2 of the field sheet packet.

Water Max Depth: Measure the maximum depth of water in centimeters in each microhabitat.

Water Open %: This field is a visual estimate of the percent of the microhabitat surface covered by open water. Open water does not include areas of surface water that are full of emergent vegetation or covered with floating mats of algae.

Substrate %: Visually estimate the percent cover of surface substrate (soil and rocks) within each range of particle sizes. These soil texture categories follow a modified logarithmic particle size scale:

- 1: clay
- 2: silt
- 3: fine sand (0.1-1 mm)
- 4: coarse sand and pea gravel (1-10 mm)
- 5: coarse gravel (1-10 cm)
- 6: small boulders (10-100 cm)
- 7: large boulders (>1 m)
- 8: bedrock
- Org: organic soil, including peat, or organic material that is at least partly decomposed. This does not include undecomposed leaf litter
- Oth: other cover, which typically includes human-built objects like pipes and spring boxes

Values for these ten substrate categories should sum to 100% for each microhabitat (see Schoeneberger et al. 2012).

Prec(ipitate) %: Visually estimate the percent cover of chemical precipitate (i.e., salt crust) in each microhabitat. In some cases, precipitate crust may cover litter and wood and can therefore be as high as 100%.

Litter %: Percent litter cover (Schoeneberger et al. 2012) is a visual estimate of the percent of the ground covered by leaves, twigs, and small downed branches (<1 cm diameter).

Wood %: Visually estimate the percent of the ground covered by logs and woody branches >1 cm in diameter. This value should only include woody debris lying on the ground, not standing dead trees and shrubs.

Litter (Depth; cm): Take three or more litter depth measurements from different areas in the microhabitat and record the average.

Images Section

The geographer should take several site photographs that capture the context and condition of the springs ecosystem under study. Such photographs also can be used for long-term monitoring comparisons. Heavy vegetation cover often obscures important site features, so selection of photo points should be carefully considered. Typically, only 1-3 site photographs are uploaded into the Springs Online database, but photographers should take several photos so that the best photos might be chosen for upload. If appropriate, additional images may be labeled and stored elsewhere.

In addition to the representative site photos, 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 Springs Online and associated with the taxon (plant, vertebrate, or invertebrate) where it is listed within the survey.

Camera Used: In this field, the geographer should identify which camera was used to take photographs of the site. The purpose of recording this information is to aid data entry staff in finding the photos. Photographs are commonly misplaced or lost during and after inventory projects.

Photo # and Photo Caption: The geographer should document photo numbers generated by the camera and describe the subject of the photograph (e.g., source pool and outflow channel). The geographer should also record the location where the photographer was standing and the direction they were facing (e.g., photographer on left bank of springbrook 10 m downslope of source, facing the source). Be clear about which notes refer to the photo subject and which refer to the photographer's position. This information will be used to compose helpful photo captions for the survey report. Cameras with GPS capability can help to identify the location and sometimes even the aspect 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, attached to the field sheets, or electronically in a GPS unit).

Sketchmap

Once the crew has discussed and defined the microhabitats, the geographer should field-map them on an ortho-rectified site photograph, on field tablet, or on graph paper (e.g., Fig. 15 and Fig. 16). The final page of the field sheet packet is printed with a grid for drawing a sketchmap, and includes a helpful checklist of details to include on the map. The map should be to scale; the geographer may use a metric tape or rangefinder to measure site dimensions. At extremely large sites, the geographer may prefer to walk the site perimeter with a GPS unit recording a track, and use that track to document the size and shape of the site. Once the site and microhabitats are outlined on the sketchmap, the geographer should add these details to the map:

- Spring name, names of surveyors and their roles, date and time of survey
- Scale bar and north arrow
- Location of springs sources and arrows showing flow direction
- Location where GPS point was recorded
- Locations of the flow, water quality, and Solar Pathfinder measurements
- Constructed features like roads, trails, spring boxes, pipes, troughs, and significant semi-permanent natural features like large trees, boulders, rock outcrops, and downed logs
- Microhabitats should be labeled with their identifying letter, name, and area in square meters
- Photo points (location and direction the photographer was facing)
- Unusual inventory finds

Be sure to collaborate with the entire team to assure that the sketchmap incorporates the observations of all team members. The sketchmap is scanned as a *.jpg file and uploaded into Springs Online and associated with the survey along with site photographs.

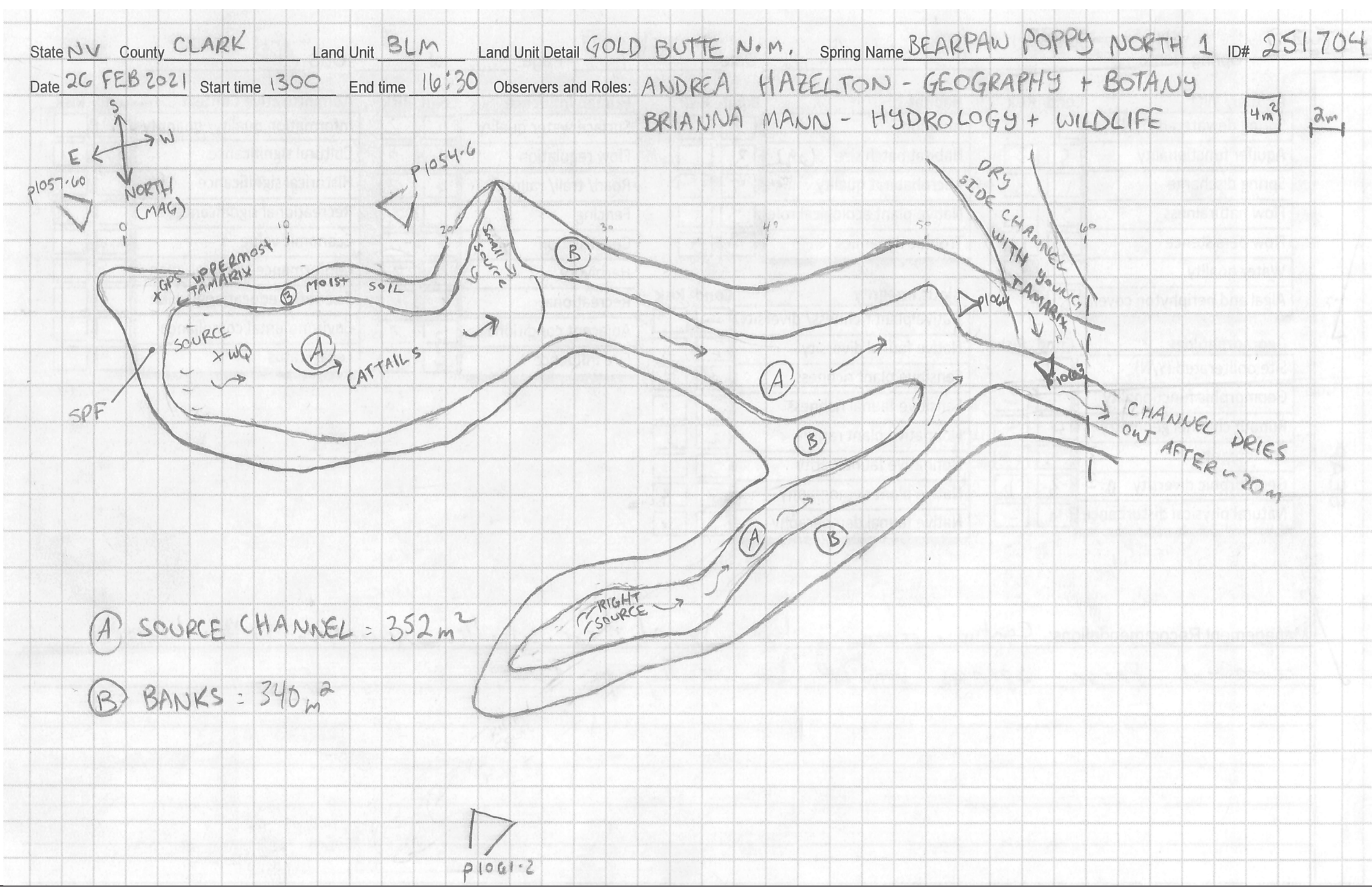


Fig. 15. Example of a field sketchmap. Bearpaw Poppy North Spring on Gold Butte National Monument, Nevada.

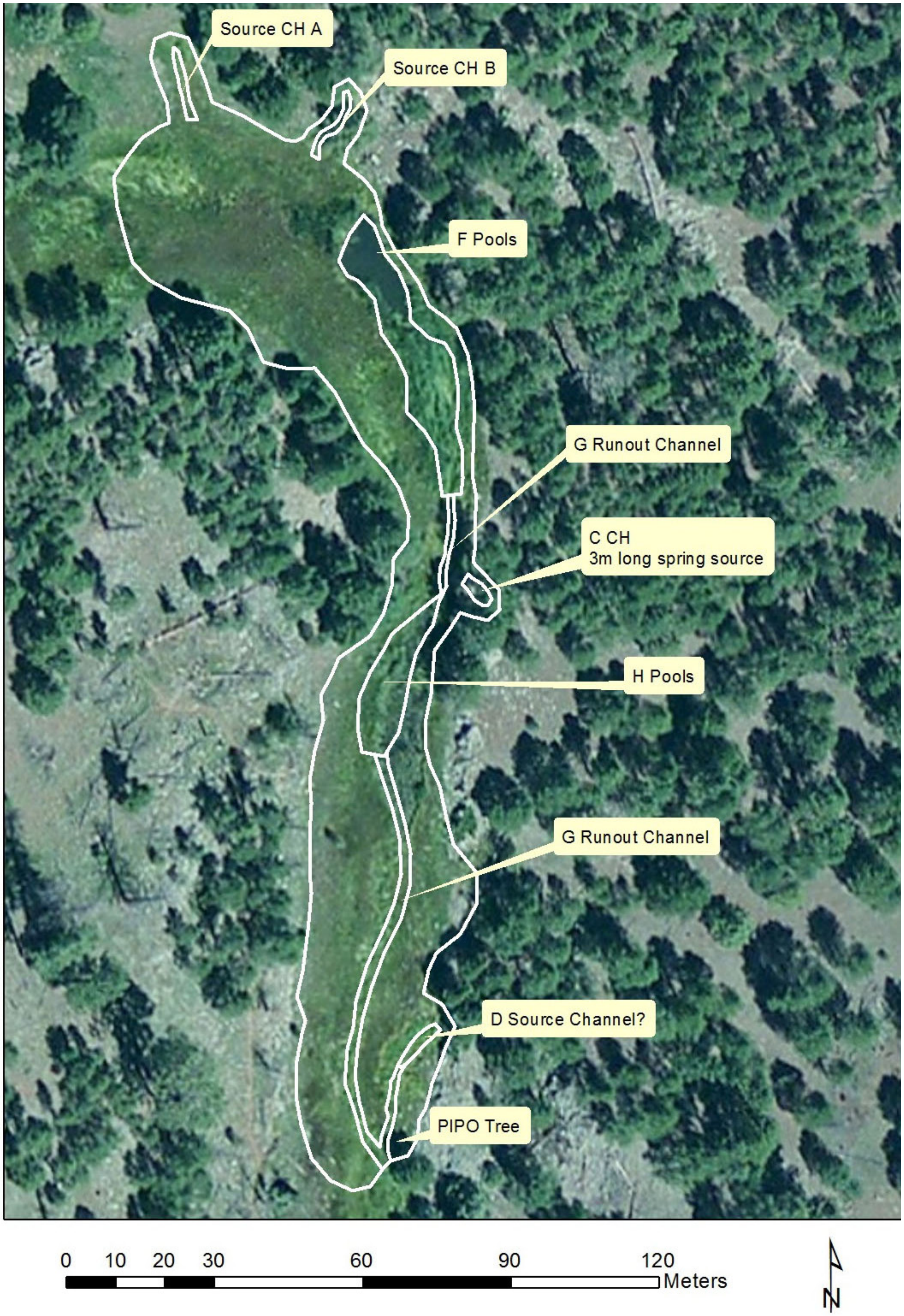


Fig. 16. Example of a sketchmap generated by walking the perimeters of microhabitats using a GPS, then bringing the data into ArcMap, refining the polygons, and adding labels. Compared to hand-drawing a sketch map, this method can be much more efficient and accurate for large, open, flat sites. It also is sometimes possible to draw microhabitats 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.

Field Sheet Page 2: Quick Reference Sheet

This page contains lists of possible responses for many of the variables in the field sheet packet. These numbered lists of possible responses correspond with the options available in drop-down fields when entering the data into Springs Online. For example, options for [1]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. 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.

Field Sheet Pages 3 and 4: Fauna

Fauna Overview

Wildlife use of springs is often surprisingly intensive. For example, GCWC (2002) reported 35 bird species, some in great abundance, watering at a small, remote spring on the North Rim of Grand Canyon in less than an hour during a Level 2 springs inventory there. GCWC (2002, 2004) reported two- to five-fold higher avian and butterfly density and species richness at springs as compared to adjacent uplands. Documenting the use of the springs by terrestrial fauna is important not only for understanding their impacts on the springs, but also for understanding the ecological role of the springs in relation to the surrounding ecosystems (Fig. 17). Although many terrestrial vertebrate species may be detected during a single site visit, developing a relatively complete species list and quantifying the use of a spring by those species requires many visits at different times of the year, a Level 3 research effort.

Aquatic and wetland faunal life at springs commonly includes Nematoda, Turbellaria, Annelida, Mollusca, arthropods (particularly crustaceans, insects, and other taxa), other invertebrates, fish, amphibians, reptiles, birds, and mammals. It is particularly important to note endemic species in spring surveys, as they are often dependent on springs ecosystems and may indicate spring health. Taxa that are particularly prone to endemism at aridland springs in the United States include: flatworms, hydrobiid springsnails (Hershler et al. 2014), physid aquatic snails, aquatic amphipods and isopods, various families of stoneflies, several families of Heteroptera waterbugs (especially Nepomorpha, e.g., Stevens and Polhemus 2008), several families of beetles (e.g., Dytiscidae, Hydrophilidae, Elmidae, Dryopidae, and others), cyprinid, cyprinodontid, and other fish (Nelson 2008), and amphibians. In addition, rare but non-endemic taxa, as well as species potentially new to science may be detected during springs surveys (Sada and Pohlmann 2006, Stevens and Meretsky 2008, Stevens and Polhemus 2008, Stevens and Bailowitz 2009, Kreamer et al. 2015). Techniques for sampling, preservation, and identification vary by taxon, requiring specific equipment, permits, preservation protocols, and considerable field and laboratory expertise. The most common of these techniques are discussed below.

Vertebrates

Level 2 vertebrate surveys are opportunistic and consist of documenting observations of all vertebrates and vertebrate signs visible at and immediately surrounding a springs ecosystem during the inventory. Formal, taxon-specific quantitative protocols (such as avian point counts, small mammal trapping, and camera traps) are Level 3 survey efforts, outside the scope of the Level 2 inventory (see Level 3 Inventory, below). While conducting a Level 2 inventory, the zoologist should also make note of any observations that might warrant Level 3 work, such as rare species or unusual habitat types.

The zoologist should spend at least five minutes at the site prior to the arrival of the other team members to observe wildlife, which is likely to subsequently disperse or have their tracks and sign obscured when the survey team arrives. When reporting vertebrate fauna at springs, the zoologist should document all aquatic and terrestrial vertebrates detected at or within an approximate 100 m radius of the springs habitat. Birds flying overhead should be recorded if they occur within a 100 m radius regardless of their height over the ground. In addition to animals that are directly observed, the

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.

Fig. 18. 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 and linked to the appropriate taxon.

zoologist should also record any animal sign observed in the 100 m radius area, such as tracks, scat, burrows, antler rubs, kills, etc.

When vertebrates are directly observed, the zoologist should record the identity of the taxon, note how many individuals were observed in the column labeled “No. Ind” (number of individuals) and write “obs” (i.e., observed) in the column labeled “Detection Type.”

When wildlife sign is observed, but live individuals of the taxon are not present and the number of individual organisms is not certain, the biologist should record the taxon name, leave “No. Ind” blank, write “sign” in the column labeled “Detection Type,” and record the type and abundance of sign (scat, track, burrow, etc.) in the “Comments” column (Fig. 18, Fig. 19).

Vertebrate taxa may also be recorded if the zoologist recognizes a call but does not visually observe the animal; in these cases, fill in “call” for detection type. If someone outside of the field crew reports having observed a vertebrate taxon at the spring, but the survey crew does not detect the taxon during the survey, the zoologist may record it on the field sheet and write “reported” as the detection type. For example, a rancher might report having recently seen a mountain lion near the spring.

The “Comments” column may be used to record details about the vertebrate observation. This might include behavior, abundance at the site, sex, type of sign observed, or distinctive markings to aid in later identification.

Spring Name Jackson Spring Date 2022-05-09 Page 2 of 8 OBS JDL for LES

Vertebrates

Fauna Notes (Including weather conditions and search effort for vertebrate & invertebrate species of concern):
Calm, air temperature 22 C.

Taxon Name	No. Ind	[13]Detection Type Call/ Observed/ Sign/ Reported (by others)	Comments
American Black Bear		sign	Tracks and scat near source
Common Raven	2	obs	
Peregrine Falcom	1	obs	Hunting nearby

Fig. 19. Field sheet used for recording vertebrate observations during a Level 2 springs inventory. The zoologist should also record any taxa that they identify as having visited the spring based on signs such as tracks or scat, as well as animal calls or reports made by others.

Fig. 20. *Metrichia nigritta* (Hydroptilidae) caddisfly mass emergence, a rare observation at Fossil Springs, Coconino National Forest, Arizona.

Invertebrates

Aquatic and terrestrial invertebrates are commonly of management interest and can occur in great abundance and diversity at springs (Fig. 20). The zoologist should be sufficiently familiar not only with invertebrate biodiversity in general, but also with all species of management concern in the study area. The zoologist also should be readily familiar with the techniques available for qualitative and quantitative sampling (described below). While the same data sheet is used to record all invertebrate observations for a survey, techniques for surveying and collecting aquatic invertebrates differ from those of terrestrial invertebrates, as discussed below.

Fig. 21. Common springs-dependent invertebrate taxa found throughout North America, displayed using appropriate preparation techniques.

As with Level 2 vertebrate surveys and regardless of which inventory method is used, a single-visit invertebrate survey is unlikely to result in a complete list of taxa occurring in the springs ecosystem. GCWC (2004) reported that six site visits during different seasons and years were needed to detect 90 percent of the macroinvertebrate taxa present. Nevertheless, rigorous qualitative opportunistic sampling of invertebrates when performed during a single site visit during the growing season generally will be sufficient to detect most aquatic macroinvertebrate species of potential management interest. As with the vertebrate survey, the zoologist should be sure to note any observations that might warrant Level 3 work, such as rare species or unusual habitat types.

With the sampling methods described below, invertebrates may be collected, documented, and immediately released if the zoologist can readily identify them (Fig. 23). Capture and release methods should be used whenever possible, particularly at small springs where small invertebrate populations might be jeopardized by scientific collecting. Of particular concern are predatory species, which are likely to be rarer than herbivores or detritivores. Nonetheless, specimens may need to be collected if taxonomic verification is needed, and appropriate methods are described below for collection and preparation of aquatic and terrestrial specimens. Surveyors may choose to retain collected specimens to contribute to a museum or a voucher collection; in some cases, the steward may require such practice. Because laboratory identification and curation of invertebrates is time consuming and expensive, we recommend development of a voucher collection for the land management unit to expedite future Level 2 surveys and Level 3 activities. Specimens should be curated and preserved in accord with long-term museum conservation standards (Fig. 21), as detailed in the Specimen Management section.

Aquatic Invertebrates

Several methods are available for Level 2 inventories of aquatic macroinvertebrates. When selecting the most appropriate method, the zoologist should consider the site configuration, conditions, safety, and project research questions.

Methods for sampling aquatic macroinvertebrates are divided into two categories: qualitative and quantitative. Qualitative sampling produces a list of taxa present at the site. Because the zoologist should search all available habitats when using qualitative techniques, the taxon list may be fairly lengthy. Quantitative sampling produces a list of taxa present at the site, with associated data on the occurrence frequency of each taxon. These quantitative data can be useful for documenting trends or performing among-site comparisons. However, quantitative methods generally limit the zoologist to sampling flowing water benthos, so the taxon list resulting from quantitative sampling will be less complete than a list generated by rigorous qualitative sampling.

Aquatic macroinvertebrates of management interest include crayfish and other invasive invertebrates, as

Fig. 23. If a specimen can be identified in the field, it typically need not be collected. This photograph of a Brechmorhoga pertinax (Masked clubskimmer) is sufficient to document the specimen.

Fig. 22. Several types of nets used to collect invertebrates. The white aerial net (left) is used to collect terrestrial insects; the tan-colored D-net (middle) is used for aquatic invertebrate sampling in lentic or lotic habitats; and the small blue aquarium net is useful for sampling aquatic invertebrates in variety of habitats including small shallow streams.

Fig. 24. Surveyors collected a predaceous diving beetle larvae attempting to feast on a grasshopper. As they could be readily identified, surveyors documented and released both. The grasshopper excaped, and the predaceous diving beetle missed lunch. These species were documented at a spring in Apache-Sitgreaves National Forest, Arizona.

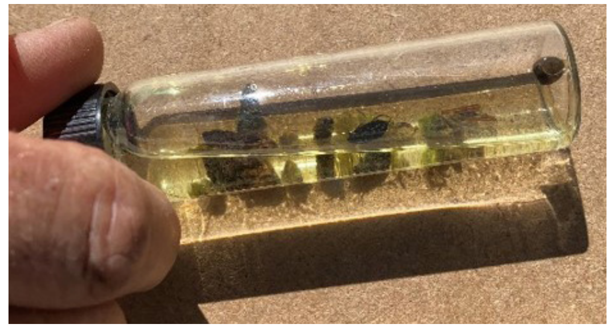
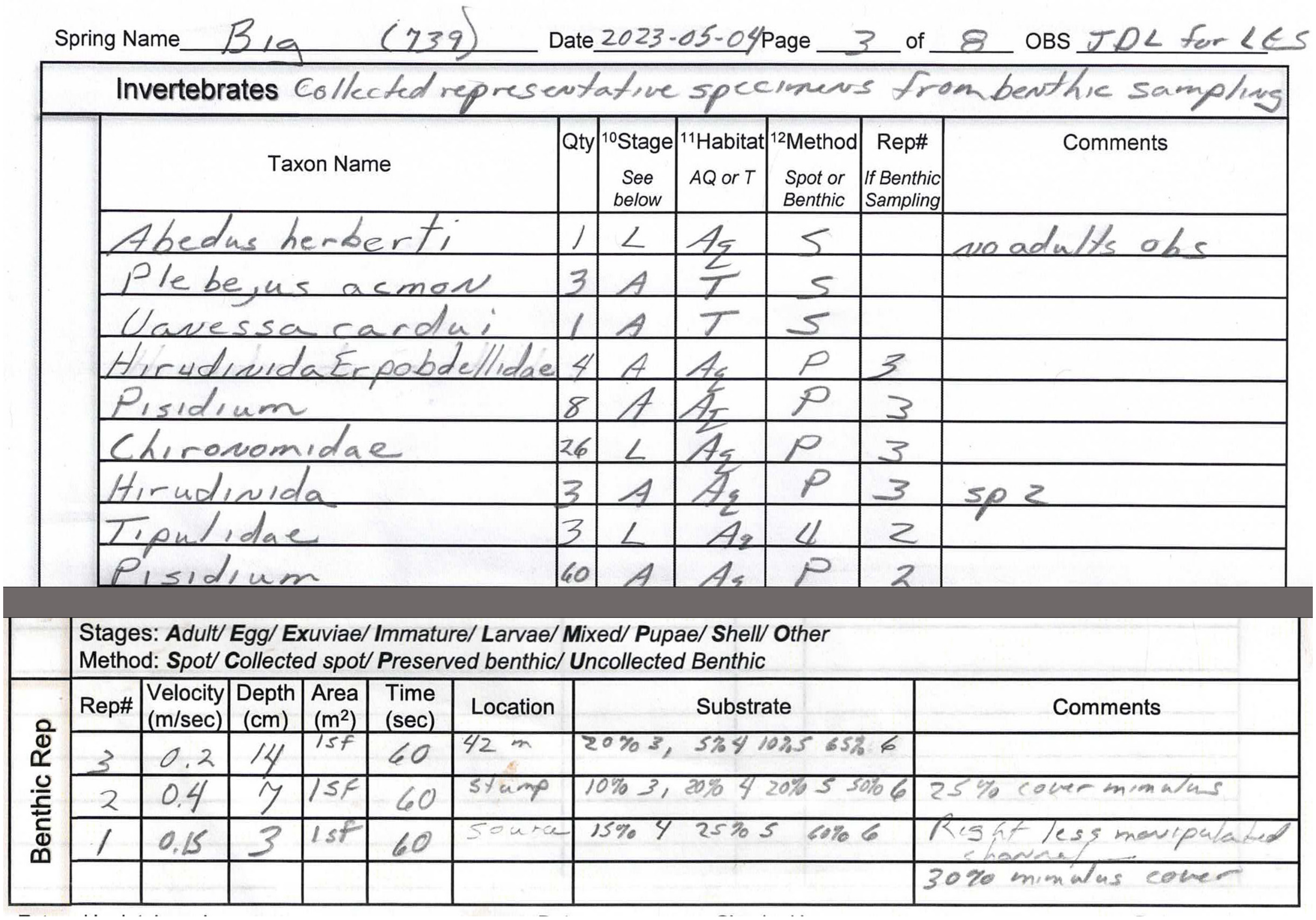


Fig. 25. This vial contains aquatic macroinvertebrates that were collected using a spot-sampling technique with an aquarium net. The biologist will place a label into the vial with the date, site name and collector's name written on it. After the vial is transported to the lab, a biologist will sort and identify the contents.

well as protected species, such as springsnails. When research questions involve species of management concern, the zoologist should understand whether a list of invertebrate taxa (or documenting presence/absence of certain species) will be sufficient to answer the project question, or if quantitative data are possible and needed. Crayfish may be sampled using qualitative spot sampling or using quantitative D-netting or seining, depending on project information needs and time available; quantitative catch per unit effort (CPUE) or area occupied are commonly used metrics to assess crayfish abundance. When protected species are present, the zoologist is expected to have reviewed U.S. Fish and Wildlife Service and State guidance about sampling around such species. It also may be necessary to obtain special research permits from the state and/or U.S. Fish and Wildlife Service to sample invertebrates at sites where sensitive species are known to occur, or potentially occur.

Qualitative Opportunistic (Spot) Sampling: Opportunistic sampling is commonly used by zoologists to develop a species list for a site. The zoologist uses a handnet (aquarium net), a D-frame net, or a sieve to sweep up benthic or free-floating macroinvertebrates (e.g., Fig. 22). Opportunistic sampling should be rigorously conducted for at least 15 minutes, and the zoologist should sample all conspicuous microhabitats, including madicolous, pool surface, water column, benthic, and hyporheic microhabitats, as well as among emergent and shoreline vegetation, under rocks and logs, and along shorelines. The zoologist may document and release all invertebrates they are able to readily identify (Fig. 24). Those specimens that the zoologist cannot readily identify may be collected, provided that such collection does not harm the local population (Fig. 25). Alternatively, organisms can be photographed. Although a photograph can provide sufficient information for identification, as with dragonflies and butterflies, identifying specimens from photographs is often imprecise.



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Invertebrates Collected representative specimens from benthic sampling

Taxon Name	Qty	10 Stage (See below)	11 Habitat (AQ or T)	12 Method (Spot or Benthic)	Rep# (If Benthic Sampling)	Comments
Abedus herberti	1	L	Aq	S		no adults obs
Plebejus acmon	3	A	T	S		
Vanessa cardui	1	A	T	S		
Hirudinida Erpobdellidae	4	A	Aq	P	3	
Pisidium	8	A	Aq	P	3	
Chironomidae	26	L	Aq	P	3	
Hirudinida	3	A	Aq	P	3	sp 2
Tipulidae	3	L	Aq	U	2	
Pisidium	60	A	Aq	P	2	

Stages: **A**dult/ **E**gg/ **Ex**uviae/ **I**mmature/ **L**arvae/ **M**ixed/ **P**upae/ **S**hell/ **O**ther
Method: **S**pot/ **C**ollected spot/ **P**reserved benthic/ **U**ncollected Benthic

Benthic Rep

Rep#	Velocity (m/sec)	Depth (cm)	Area (m²)	Time (sec)	Location	Substrate	Comments
3	0.2	14	1sf	60	42 m	20% 3, 5% 4 10% 5 65% 6	
2	0.4	7	1sf	60	stump	10% 3, 20% 4 20% 5 50% 6	25% cover mimulus
1	0.15	3	1sf	60	source	15% 4 25% 5 60% 6	Right less manipulated channel
							30% mimulus cover

Fig. 26. The Invertebrate field sheet is used for recording invertebrate observations during a survey. In this example, surveyors conducted three reps, documenting the sampling information at the bottom of the sheet and entering the Rep# for each species ccaptured in the net. The recorder who completed the sheet entered initials in the OBS field, as well as those of the zoologist.

The zoologist documents on the field sheet the name of each taxon collected or observed, as well as an estimate of the number of individuals and life stage of each taxon (Fig. 26). Springs Online accepts any of these nine invertebrate life stages: adult, egg, exuviae, immature, larvae, mixed, pupae, shell, and other.

The zoologist also documents the collection method. Options in Springs Online include:

- **S**pot - species documented but not captured
- **C**ollected spot - species collected using opportunistic sampling
- **P**reserved benthic - specimen, or a representative sample, collected using quantitative sampling
- **U**ncollected benthic - specimen documented but not collected, either because it could be readily identified, or would not be possible to identify.

The zoolotist also documents habitat type occupied by each species (**Aq**uatic or **T**errestrial). If the zoologist collects a number of unknown taxa for later identification, it is sufficient to write "see vial" or "see collection" on the field sheet, and the zoologist may subsequently record the species on the sheet once they are identified.

The qualitative opportunistic (spot) sampling method is especially useful at sites where there is too little flowing water to allow the zoologist to use the quantitative methods described below. It also may be appropriate when the research question or management goal requires the zoologist to identify a list of invertebrate taxa present at the site, or document the presence/absence of species of management concern if the quantity or density of individuals is unimportant.

Quantitative Benthic Sampling: If sufficient stream flow exists (flow greater than 2 cm deep across a channel exceeding 10 cm in width), a timed quantitative benthic sampling method may be appropriate. These methods allow the zoologist to estimate a baseline rate of encountering individuals (quantified as the number of individuals per square meter per minute of sampling time), as well as species encounter rate (number of species per square meter per minute). The zoologist will select the most suitable sampling equipment based on habitat, but the basic method of quantitative benthic sampling is the same for all sampling gear (e.g., kicknet, Surber sampler, Hess basket, or dredge). The sampling device is held in the water for a specified time period (typically one minute). When sampling the benthos, the zoologist physically disturbs the benthos in a known area (e.g., 0.09 m^2) immediately upstream of the sampling equipment, and then harvests the material that has accumulated in the net. Once the net is removed from the water, the zoologist places the sample in a sorting pan, identifies all invertebrate taxa that were caught in the net, and counts and records the number of individuals of each taxon. The captured organisms should be released once the tally is completed. If local populations are not threatened, the zoologist should preserve one or a few individuals of each taxon encountered to serve as vouchers. Alternatively, but only if sampling without replacement does not threaten local populations, all material captured in the net can be placed in a container with 80% ethanol and returned to the laboratory for sorting and enumeration. For all quantitative methods, sampling is replicated at least three times (three "reps" per spring). If substrata are diverse, additional sampling may be warranted, as time permits. Be sure to record any "zero" samples that lack any invertebrates, assuming the samples were properly collected.

Those specimens that the zoologist cannot readily identify may be collected and transported to the lab for identification. Collection and handling techniques for invertebrate specimens are discussed below.

In addition to recording the taxa captured and the number of individuals of each, the zoologist should record the duration of the sampling event for each replicate and the area sampled (in m^2). On the invertebrate field sheet, the upper section is used to record all taxa observed or collected using any sampling technique, and there is a column to note whether the sampling method was qualitative or quantitative, and whether specimens were retained (Fig. 26).

For quantitative benthic sampling techniques, the zoologist should also fill in the Rep# column for each observation. In the separate section at the bottom of the page, the zoologist records the details of each replicate sample. The zoologist should describe the location of each replicate, and characterize each location by recording the stream velocity, stream depth, particle size distribution of the channel bed, water quality, and dominant algae or vascular plant cover.

Quantitative benthic sampling is performed sequentially in an upstream direction to limit error related to downstream drift of disturbed invertebrates into the sampling net. A dredge (e.g., a Petite Ponar dredge) is designed to sample in standing water, but all other equipment described below requires flowing water. The following sampling equipment is commonly employed in aquatic invertebrate sampling:

Kick-Net (quantitative benthic sampling): The kick-net sampling technique is a quantitative method that is used in flowing water for channels with water depth greater than 2 cm. A kick-net is a sheet of netting that is stabilized on two sides by poles (Fig. 27). The standard size is 1 m by 1 m, but smaller nets (mini kick-nets) are available for use in shallow streams. Hold the kick-net on the stream floor perpendicular to the current, setting the pole ends firmly into the sediment to stabilize it. The zoologist should then vigorously disturb the sediment in a measured area (often 0.09 m^2 or 1 m^2) upstream of the net with a trowel or probe for a specified time period (usually one min). Ideally, the zoologist will mark the area to be disturbed with a frame. Rotate and scrape the gravel and cobble substrates 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 disturb a 1 m^2 area of benthos for one minute. For water depths of 0.1 - 0.5 m, use a

Fig. 27. A kick-net, used for quantitative benthic sampling. This net has an area of one square meter. A smaller net should be used where water depth is less than 50 cm.

mini-kicknet or a D-net, and sample a smaller area (often 0.09 m²) for one minute. Very shallow channels that have several cm of flow can be sampled with a 15 cm wide, 0.5 mm mesh aquarium dip net. With all methods, be cautious to ensure that the flow successfully delivers specimens into the net.

Surber Sampler (quantitative benthic sampling): A Surber sampler can be used to collect macroinvertebrates in spring channels with water depths of about 5 to 50 cm. Orient the opening of the device upstream into the current, stabilize the net by placing a foot on one corner, and as with the kick-net, vigorously disturb the sediment within the frame upstream of the net with a trowel or a probe for a specified amount of time (typically one min). If there are cobbles within the sampling frame, the zoologist should pick up each cobble and gently rub to dislodge any invertebrates that are attached to it. Dislodged macroinvertebrates will passively float downstream into the collecting device at the end of the net (Fig. 28).

Hess Basket (quantitative benthic sampling): Hess basket samplers are used in wadeable lotic settings. The sampler is a cylindrical tube with a screen on the front (upstream) side and a net on the back (downstream) side (Fig. 29). It can be covered or not, with a gasket that allows access when used in water that overtops its rim. The zoologist places the basket on the channel floor and stretches the net out on the downstream side. The zoologist vigorously agitates the substrata within the footprint of the basket for a set amount of time (typically one min). Benthic materials and species are entrained into the stream current and swept into the basket net.

Hess samplers have the advantage over Surber samplers of excluding drifting matter, so the sample collected more truly represents the benthic assemblage.

Fig. 28. A Surbur Sampler, used for quantitatic benthic sampling. The device is placed in-channel with the frame (right) in the upstream direction. The surveyor disturbs the benthos within the frame, and the stream washes the dislodged invertebrates into the net.

Fig. 29. A Hess basket is used for quantitative benthic sampling of invertebrates in wadeable streams. Hess baskets are designed to collect material as the zoologist disturbs the benthos, while excuding matter in the water column that drifts from upstream.

However, Hess samplers have the disadvantage of being more awkward to transport.

Dredge (quantitative benthic sampling): Dredge sampling is used in lentic or slow lotic settings that are too deep to sample with nets or other means (Fig. 30). These are typically pool-like habitats floored with fine-grained sediments. Several types of dredges are available, including Petite PONAR Grab, Ekman, and Van Mud dredges. The zoologist drops the dredge on a cable and records the water depth. The zoologist then hauls up the sample, dumps it into a container, and sieves it at the desired mesh sizes (often 0.5 or 1.0 mm). For

Fig. 30. A Petite Ponar Dredge.

quantitative invertebrate sampling, the zoologist uses forceps to extract invertebrates from the sieved dredge sample, and then identifies and enumerates those specimens. Dredge samples are commonly standardized based on the area of benthos sampled. For example, a Petite PONAR dredge samples an area of 0.25 ft^2 or 0.09 m^2. However, for more precise quantification of invertebrate density, the zoologist may choose to standardize the sample based on its mass or based on the volume of the sediment in the sample.

In addition to the quantitative sampling technique described here, dredge sampling may be used for a variety of analyses of the benthos. These include documenting particle size distribution, nutrient analysis, identifying and quantifying macrophytes, and calculating standing stock (i.e., biomass per unit area). However, we regard such detailed analyses as Level 3 efforts, and described them in more detail in the Level 3 Inventory section, below.

Preserving Aquatic Macroinvertebrates: With the exceptions noted below, aquatic and soft-bodied invertebrate specimens should be placed in a vial or Whirl-Pak® bag filled with 80% ethanol for transport from the field to the lab. Be sure that the concentration of ethanol is sufficiently high to withstand potential dilution due to water added from the sample. Samples collected by quantitative methods will contain a substantial amount of substrate in addition to the macroinvertebrates. If this is the case, remove the coarse substrate from the sample in the field to prevent damage to the specimens in transport (Fig. 31).

Label each bag or vial with the site name, date, collector name, substrate or habitat affiliation, and rep number if applicable. This label information may be written in pencil on a small piece of high quality paper and placed inside the sample container. The ethanol will not dissolve the paper or the writing on it. This label should be created and placed inside the sample container immediately; secondarily, the outside of the container may be labeled with a permanent marker, but this writing smudges easily, especially in the presence of ethanol.

Return the specimens to the laboratory for sorting, enumeration, and identification. If quantitative benthic or tow-net samples are collected, they can be crudely sorted and enumerated in the field (a less precise but more cost-effective practice). For each morpho-species needing taxonomic verification, the zoologist should preserve a minimum of three individuals or diagnostic portions. However, do not collect specimens if such actions threaten local population integrity.

Fig. 31. Coarse substrate materials should be removed from samples in the field to prevent damage to the specimens.

Several groups of aquatic invertebrates require preservation methods that differ from the general protocols (above). For example, identification of Ostracoda specimens and other micro-crustaceans is improved if the specimens are preserved in formalin. Leeches and other Annelida specimens should be relaxed in Alka Seltzer before preserving in ethanol. If genetic analyses are anticipated for some specimens, the entire sample should be preserved in 95-100% ethanol in sterile, inert containers, and stored in a dark, refrigerated environment until processing. Alternatively, some laboratories request that specimens be air-dried and kept in a desiccated environment.

Springsnail and other Aquatic Mollusca Collection and Preparation: Due to the difficulty identifying springsnail and other aquatic mollusk species morphologically, specimen collection is often needed to verify population status (Fig. 32). For newly discovered populations, collecting specimens is needed for genetic analysis as well as dissection for morphological analysis of soft parts (see collection protocols, below). Populations when discovered often are large; however, collecting should only be conducted if the population can withstand removal of 100 specimens.

Springsnail collection techniques for genetic and morphological analysis are described in Hershler and Liu (2017: 5-6):

> **"Freshwater truncatelloidean snails usually are locally abundant, enabling ready collection of sizeable samples (i.e., >100 specimens). A portion of each sample should be directly preserved in concentrated (90-100%) nondenatured ethanol; half of these specimens can be subsequently (air-) dried and designated as shell vouchers while the rest can be retained (in ethanol) for possible DNA analysis. The remaining portion of the sample should be anesthetized (relaxed) with menthol crystals (prior to fixation and preservation) to facilitate examination of soft parts required for identification. Menthol is an organic compound obtained from mint plants that is readily available in crystalline form from chemical supply houses. Relaxed material is particularly useful for study of the penis, while pertinent details of the female genitalia usually can be obtained from contracted specimens that were directly preserved in ethanol. Snails should be relaxed in a large container (e.g., a 1-pint [473 ml] Mason jar) that is nearly filled with habitat water and kept cool and out of the sun. A small quantity (about half a teaspoon) of powdered menthol crystals should be sprinkled over the water surface, after which the container should be capped and left undisturbed. The snails usually require about 13 hours for proper relaxation, although some species (e.g., *Pyrgulopsis robusta*) may require considerably more time. Once the specimens are anesthetized, at which time the head-foot is well extended and insensitive to touch, most of the water should be decanted and dilute formalin (10% of stock solution) should be slowly added. After 4-6 hours of fixation, the material should be rinsed and preserved in 70% ethanol.**
>
> **Alcohol-preserved snails are separated from their shells by placing them in a small quantity of concentrated hydrochloric acid. The appearance of the distal portion of the oviduct—whether it is glandular…or thin-walled and containing brooded young…can be readily determined without dissection. The bursa copulatrix can be viewed by pinning the animal, cutting the mantle along the left side of the head-foot, and pulling this tissue over… to expose the oviduct and associated structures... The penis is attached to the "neck" of the snail behind the snout and usually extends beyond the mantle edge…; both the upper (dorsal) and lower (ventral) surfaces of the penis should be examined for glands, which are relatively large and quite obvious; the internal penial glands of amnicolids are clearly visible in appropriately prepared specimens…We recommend that workers practice the methods of anesthetizing, preserving, and dissection using (commonly found) snails before applying them to essential specimens."**

Rearing Aquatic Macroinvertebrates: Larval and pupal stages of macroinvertebrates are more difficult to identify than are adults. Therefore, it is sometimes useful to rear late-stage larvae or pupae to the adult stage for identification purposes. For example, late instar 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. Keep living specimens cool to minimize transport trauma. For detailed rearing instructions, please consult Triplehorn and Johnson (2005) and Merritt et al. (2008).

Fig. 32. The dozens of springsnail species endemic to the Great Basin Desert are identified using microscopic morphological analysis and genetic analysis. Both analyses require specific specimen preparation procedures.

Terrestrial Invertebrates

Documenting the use of the springs by terrestrial fauna is important for understanding the ecological role of the springs ecosystem. Terrestrial invertebrate species occupy wetland, shoreline, and riparian vegetation niches around the periphery of springs. In a Level 2 survey, the zoologist records all species observed, along with the number of individuals (the "Qty", or quantity column on the data sheet), and the life stage of the organism. While the zoologist will gather some terrestrial invertebrate data by simply observing the site, using one of the collection methods described below will produce a more complete species list. As with aquatic invertebrate sampling, terrestrial invertebrate collection techniques can be performed quantitatively, by controlling and recording sampling effort and counting the number of individuals collected; or the techniques can be performed opportunistically for a qualitative dataset. Invertebrates collected using these methods can be released back into the field if identification is satisfactory, or they may be retained for taxonomic verification and contribution to a voucher collection or museum. Methods for properly preserving terrestrial invertebrate specimens are described after the collecting methods.

Sweep Netting: Use the sweep net technique to collect terrestrial invertebrates from vegetation, including small trees, shrubs, grass, and annual plants (Triplehorn and Johnson 2005). The zoologist swiftly swings the net back and forth as they move through vegetation. To perform this method as a quantitative sampling technique, the zoologist samples one uniform vegetation type at a time, for a set amount of time (typically for one minute) and records the results of each sample separately on the data sheet. While this quantitative technique is more appropriate for Level 3 inventory, sweep netting can also be performed as an exploratory/ opportunistic sampling technique during a Level 2 survey. It is particularly informative for detection of adult stoneflies and caddisflies.

Terrestrial Spot Collecting: Use additional techniques of opportunistic (spot) collecting for terrestrial invertebrates that cannot be collected using the sweep net technique. This includes searching for invertebrates on tree trunks, under rocks, logs or fallen branches, in leaf litter, and in flight. Collect small or venomous macroinvertebrates with forceps. Flying macroinvertebrates (i.e., tiger beetles, butterflies, dragonflies, and pollinators) can be captured with an aerial net. Note the 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 plant when disturbed (e.g., spiders, 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 vigorously to cause the macroinvertebrates to fall from the vegetation onto the net (Triplehorn and Johnson 2005).

Other Survey Methods: Nocturnal spot sampling and 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. Nocturnal aquatic sampling will 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. UV light trapping in particular may be the only technique to detect some taxa, such as adult caddisflies.

Collecting and Preserving Terrestrial Invertebrates: Prior to terrestrial macroinvertebrate collection, make sure the collecting nets are free from propagules from previously visited sites, and prepare the appropriate vial(s) of ethanol and/or a kill jar. Ethyl acetate (a commonly used killing agent) should be periodically added to the kill jar, with Plaster of Paris or an absorbent cloth as an absorbing medium. Where possible, the zoologist should make sure that a sufficient number of individuals are collected to ensure identification; however, limit collecting of rare species so as not to endanger any local population.

Once the specimens are captured, move them to the bottom of the net and transfer them to a kill jar. Hard-bodied specimens can then be placed in envelopes. Be sure to keep these dry-preserved specimens desiccated to prevent mold development. Lepidoptera (butterflies and moths) and bees (Hymenoptera: Apoidea) specimens in particular should be collected dry and placed in envelopes, not into ethanol because the alcohol disrupts scale and hair patterns. However, adult mayflies, stoneflies, and caddisflies should be preserved in 80% ethanol for ease of dissection for identification. Spiders, larvae, and other soft-bodied forms or life stages should be preserved in 70% ethanol. Specimens that are collected together (e.g., copulating, predating, or in symbiosis) should be placed in the same envelope or vial

Fig. 33. Both the *Argia* damselfly and the mites living on it are preserved in the same vial of ethanol for identification.

for transport to the lab (Fig. 33) Each envelope or vial should be labeled with the collection location, date, collector, and notes on habitat, behavior, and status (e.g., in copulation, eggs, or parasitoid). For specimens stored in envelopes, the label information should be written on the outside of the envelope. For specimens stored in vials, write label information in pencil on a small piece of paper and placed it inside the ethanol vial. Once specimens are properly labeled, they may be transported back to the laboratory for enumeration, identification and, if desired, preparation for curation.

Field Sheet Pages 5 and 6: Vegetation

Overview

Springs vegetation typically is composed of a complex of aquatic, wetland, riparian, and upland species, and can occur in unique combinations, often with co-existing rare, common native, or non-native species. Vegetation characterization is often the most time-consuming element of rapid field inventory and assessment. However, for many study sites, projects, and most springs types, it can be highly informative. The goal of the vegetation survey in the Level 2 protocol is to quickly and comprehensively describe vegetation composition, structure, and function at a springs ecosystem. To achieve this end, we recommend visual estimation of percent cover (VE%C) of each species, with VE%C for species recorded separately for six strata (Fig. 34).

VE%C methods used for floral rapid inventory are modified from Daubenmire (1959), Bailey and Poulton (1968), and Bonham (2013). This approach is considered semi-quantitative; in contrast to the use of cover classes, this method allows subtle differences in cover between species to be documented quickly.

VE%C requires detailed knowledge of local flora, as well as considerable practice in estimating foliar cover, data which are unreliable 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. Inventory staff collecting VE%C data 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 most accurately estimated through discussion among participating staff, and with increasing experience.

Other quantitative techniques exist for measuring and monitoring vegetation, such as the establishment of transects or plots, or marking individual plants (e.g.,

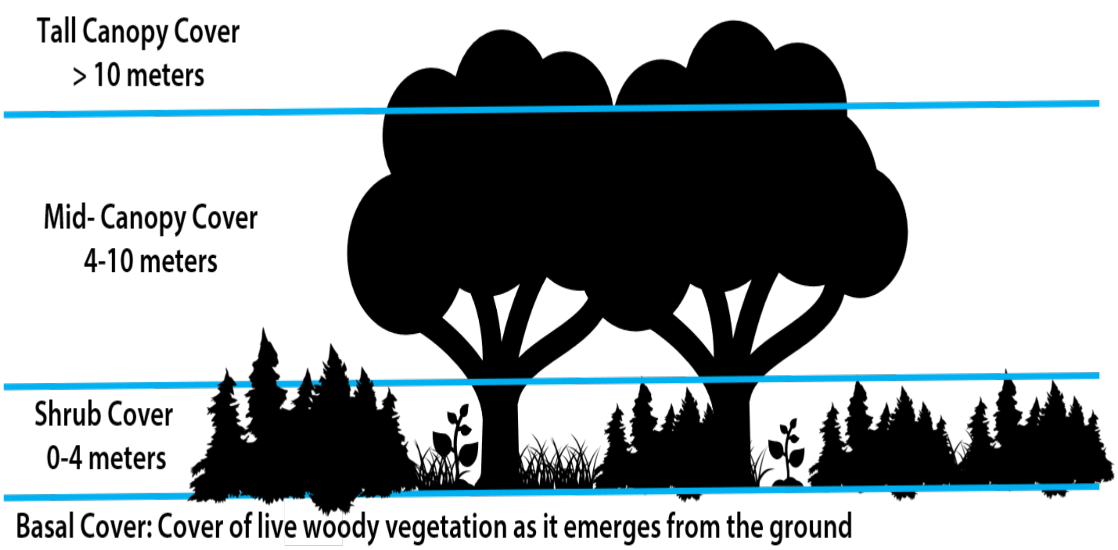


Fig. 34. Strata used for characterizing woody vegetation structure. Within each stratum, the botanist records a visual estimate of cover for each woody species. Herbaceous species can only be recorded in the ground cover stratum (GC), no matter how tall they are. Algae, moss, and lichen are recorded in the non-vascular stratum (NV), regardless of substratum.

Barbour et al. 1987, Bonham 2013), but such methods are more time consuming and expensive than VE%C, and may miss or misrepresent rare species. The inefficiency of these quantitative techniques makes them inappropriate for Level 2 inventory and assessment, but such techniques may be appropriate for Level 3 research and monitoring efforts.

Vegetation Data Collection

Before beginning vegetation data collection, the botanist should communicate with the rest of the field crew, particularly with the geographer, about the location and extent of the microhabitats. This is crucial because the microhabitats are treated like quadrats for the vegetation data collection; that is, each is characterized separately in terms of species composition and cover.

The botanist should create a list of plant species at the site on the field sheet. The botanist then estimates VE%C for each species by cover code (stratum) in each microhabitat (). Cover codes are the following:

- non-vascular (NV)—mosses, liverworts, and lichens
- ground cover (GC)—herbaceous plants of any height, including graminoids (grasses and sedges)
- basal cover (BC)—live woody stems > 10 cm diameter emerging from the ground
- shrub cover (SC)—woody plant cover within the stratum 0-4 m above the ground
- middle canopy (MC)—woody plant cover within the stratum 4-10 m above the ground
- tall canopy (TC)—woody plant cover >10 m above the ground

In regions dominated by tall trees (e.g., rainforests), very tall canopy (VTC) also may be considered.

Note that an individual plant may occupy several strata. For example, a cottonwood tree may be present as seedlings (ground cover), and mature trees may occupy shrub, mid- and tall-canopy space. While we use the terms cover code and stratum interchangeably, only woody species may occupy more than one stratum. Herbaceous species can only be recorded in the ground cover stratum, no matter their height. Woody vines and mistletoe can occupy shrub, mid- or tall canopy space.

Note also that total VE%C should not exceed 100% per stratum in each microhabitat. Only cover of live plants should be recorded. If there is notable cover of identifiable, dead plants at the site, the botanist should record this information in the "Flora Notes" field at the top of the vegetation field sheet (Fig. 35).

Plant Specimen Collection

Plant species that cannot be identified on-site by the crew botanist should be documented on the field sheet using a collection number or a distinctive code name. The botanist should harvest a quality specimen and preserve it in a plant press (Fig. 36). Each plant specimen should be pressed in its own sheet of newsprint and labeled, at the very least, with the spring name, date, and the collection number or distinctive code name that was assigned to the plant on the field sheet.

If the unknown plant is a small annual, several individuals should be collected. For larger plants, be sure to collect enough material for identification. This generally includes leaves, flowers, and fruits at a minimum; if feasible and appropriate, roots or rhizomes and stems and/or bark should be collected. If only one individual

Page ____ of ____ OBS AFH

Spring Name Mermaid Spring Date 6 May 2020

Flora Notes A=Source Pool, 102 m² C= Outflow channel, 23 m²
B= Pool Margin, 61 m²

Str (Vegetation Cover Codes)
For herbaceous plants:
NV- Nonvascular (moss, liverworts, lichen, algae)
GC- Ground Cover (all terrestrial and aquatic herbaceous veg, incl. forbs, grasses, graminoids)

For woody shrubs and trees:
SC- Shrub Cover (0-4 m stratum)
MC- Midcanopy (4-10 m stratum)
TC- Tall Canopy Cover (>10m stratum)
BC- Basal Cover (record if >1% of cover)

Coll?	Species Name	[14]Str	A	B	C	D	E	Comments
	Populus fremontii	BC	--	2	--			
		SC	5	35	--			
		MC	2	20	--			
	Anemopsis californica	GC	30	10	--			
	Algae	NV	40	0.5	3			
AH 932	Small blue-flw monocot	GC	--	1	1			Blue-eyed grass??

Fig. 35. Example of a vegetation field sheet. Note that there are three rows of entries for Populus fremontii, a tree species. The botanist recorded cover separately where the tree intersected three different strata: basal cover, shrub cover, and mid-canopy cover. Also note the bottom entry, where a collection number and code name were assigned to an unknown plant.

of a species is detected on a site, it is best to photograph it rather than collect it. The same is true for sensitive species (Fig. 37).

Plant specimens may be collected and placed in plastic bags while at the field site, but should be transferred to a plant press as soon as possible. This is necessary to protect the specimen from damage and mold, and to keep collected plants organized and properly labeled. When pressing plant specimens, place at least one blotter or cardboard between specimens in the plant press. As the plants dry in the press, periodically replace blotters to help the specimens dry and prevent mold development. Plant presses should be kept dry and in conditions that allow the specimens to dry as quickly as possible. In humid regions it is necessary to place the plant press in a plant dryer immediately after returning from the field in order to properly dry the specimens.

Algae, liverworts, mosses and other non-vascular plants can be collected if the steward is interested in taxonomic identification to species for these taxa. 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. Vascular aquatic plants often are best pressed on wax paper and placed in a plant press to prevent the specimen from sticking to the newsprint.

Fig. 36. Tools used to collect and preserve plant specimens: digging knife, clippers, and plastic bags to preserve specimens until they are put in the plant press.

Fig. 37. If only one individual of a species is detected on a site, or a sensitive species is detected, it is best to photograph rather than collect it.

Field Sheet Page 7: Geomorphology, Solar, and Flow Measurements

Geomorphology

The geomorphology section of the field sheet includes several data fields to describe the spring's geomorphic and geologic setting in a standardized format.

Emergence Environment: The environments into which spring sources emerge are grouped into these categories, which are also listed on the field sheet:

- Cave– Subterranean sources that may only be indirectly exposed to the atmosphere.
- Subaerial– Above-ground emergence. This is the most common emergence environment for surveyed springs.
- Subaqueous: Lentic freshwater– Aquatic emergence directly into a lentic water body (pond or lake).
- Subaqueous: Lotic freshwater– Aquatic emergence into a lotic environment, such as a stream or river.

- Subaqueous: Estuarine– Aquatic emergence into an estuarine environment.
- Subaqueous: Marine– Aquatic emergence into a marine environment.
- Subglacial– Above-ground emergence beneath a glacier.

Source Geomorphology: This data field describes the underlying structure that allows the spring to flow. The following five categories are available to describe source geomorphology:

- Contact—Groundwater discharges along a stratigraphic contact or bedding plane, usually in sedimentary rock.
- Fault—Groundwater is exposed at or discharges from a fault (i.e., a fracture or zone of fractures at which there has been displacement of the stratigraphic layers).
- Fracture–Groundwater is exposed at or discharges from geologic joints or fractures.
- Seepage or filtration–Groundwater is exposed at or discharges from numerous small openings in permeable material.
- Tubular or conduit—Groundwater is exposed or discharged from the openings of solution passages or tunnels.

Flow Force Mechanism: The forces that bring water to the surface may not be evident on a single visit, and it may be necessary to obtain additional information about subsurface water from surrounding wells.

Typically, most springs are gravity fed. However, flow from some springs is forced out by artesian pressure, geothermal heat, or gas-producing chemical reactions. Some springs do not flow and are not subject to pressurized discharge, while others have multiple forcing mechanisms. Anthropogenic factors, such as groundwater loading around large reservoirs, may create forces that anthropogenically affect springs emergence. Keep in mind that additional data may be needed to determine the forcing mechanism

- Gravity—Most springs are gravity-driven. The water flows out of the ground without being forced by pressure other than the force of gravity.
- Artesian—Artesian springs discharge water that is under pressure. The flow issues from an aquifer that has an upper confining layer putting pressure on the water. When the aquifer is under greater pressure than the force of gravity at the point of discharge (i.e., head pressure differential), an artesian spring will flow.
- Geothermal—These are springs associated with volcanism. Geothermal springs emerge when groundwater comes in contact with magma or geothermally warmed crust and is forced, sometimes explosively in geysers, to the surface.
- Anthropogenic—These are springs created by anthropogenic forces. For example, groundwater loading around large reservoirs may create forces that anthropogenically affect springs emergence.
- Other— Spring emergence due to pressure produced by other forces. For example, "coke bottle" springs are driven by constant gas build-up and release.

Channel Dynamic: Examine the morphology of the channel (if a channel exists) to determine if it is dominated by springs discharge, by surface flows, or by a mixture of both.

- Spring dominated— Channels created and dominated by springs discharge are typically linear, non-symmetrical features that are slightly incised, with base flow near the bankfull stage (Griffiths et al. 2008; Fig. 38). This morphology develops be-

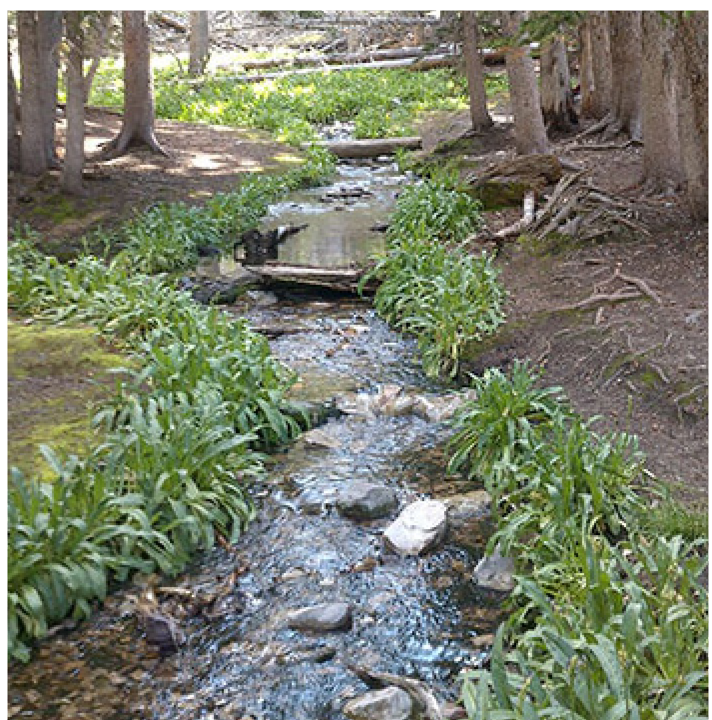


Fig. 38. The outflow of Teresa Lake Spring in Nevada forms a springflow-dominated channel. The path of the channel is relatively straight, and the springflow fills the channel to near the bankful stage.

cause springs discharges have insufficient power to transport larger particles, logs, or other channel obstructions. Flow moves linearly down a channel until it deflects off individual boulders or logs; this deflection causes channels to become non-symmetrical. Thus, a springflow dominated channel typically lacks sinuous meanders and pronounced terraces until it passes some distance downstream, where it is overtaken by surface flow processes. The springbrook is defined as the springs outflow channel from the source downstream to the initiation of sinuous surface-flow generated meanders. Springbrook geomorphology is unique to springs-dominated drainages, forming in relation to the gradient, bed material composition, discharge rate and variability, vegetation, and other factors.

- Runoff dominated—If a channel is surface-flow (runoff) dominated, the channel typically is oversized in relation to the baseflow derived from the spring, with regular sinuosity, well-formed terraces, varying extent of incision, and sometimes with well-sorted bed materials. Typically, there are two bankfull stages: a small, slightly or not incised channel for the springs baseflows, within a larger, wider channel with distinct terraces created by regular surface flooding (Rosgen 1996). Consider a small spring emerging in a dry riverbed: often, there are strandline piles of flood debris on the terraces of runoff-dominated channels.
- Mixed— The channel geomorphology of relatively large rheocrenic springs emerging in relatively small surface flow channels may exhibit characteristics of both springs- and surface-dominated channels.
- N/A—Select this option if the spring lacks a runout channel.

Rock Type/ Subtype/ Geologic Unit: Describe the stratigraphic unit from which the spring source issues. To answer this question accurately, it is helpful to review a stratigraphic column, geologic map or GIS geology layer of the study area when preparing for field work. Other basic tools available to surveyors are a hand lens, rock color charts, and 10% HCl, which will fizz when a drop is placed on the fresh, unweathered surface of a carbonate-rich rock.

- Rock Type (primary lithology)—Responses are limited to igneous, metamorphic, sedimentary, unconsolidated, and combination.
- Rock Subtype (secondary lithology)—Examples of appropriate responses include sandstone, basalt, limestone, andesite, and shale.
- Geologic Unit (geologic layer)—Examples of appropriate responses include Kaibab Limestone, Coconino Sandstone, Moenkopi Formation, and Vishnu Schist.

Solar Radiation Budget

The Solar Pathfinder (SPF) is a simple device used to estimate the percent of the sky that is blocked from direct sunlight at a specific location (in our case, at a spring source; Fig. 39). This information, which is recorded as the average time of sunrise and sunset each month of the year, is used to estimate the potential amount of photosynthetically active radiation (PAR) reaching a springs ecosystem (Solar Pathfinder Inc. 2016).

PAR is a driving factor for all ecosystems, as it represents the amount of light available for plant growth

Fig. 39. A Solar Pathfinder is used to estimate monthly photosynthetically active radiation (PAR) at a spring ecosystem.

and influences the duration and frequency of freezing in winter and evaporation rates and relative humidity in the summer months. In open terrain, PAR can reasonably be estimated without a field measurement, using GIS models available from sources such as the National Renewable Energy Laboratory (NREL). However, springs frequently occur in topographically complex terrain. In order for a PAR estimate to accurately reflect conditions at a spring in topographically complex terrain, it is necessary to estimate the amount of sky blocked by local topographic features and adjust the "open sky" PAR estimate accordingly. A Solar Pathfinder measurement, which takes one to two minutes, provides the data to accomplish this task. Springs Online uses data from the Solar Pathfinder reading to calculate the percent of available solar radiation that reaches the site and estimates the quantity of solar radiation (in megajoules) that reaches the site annually. These calculations can also be made in excel or using proprietary software from the Solar Pathfinder manufacturer.

The Solar Pathfinder sunrise and sunset time estimates are accurate to within about 0.5 hours. Before taking a Solar Pathfinder reading, it is necessary to adjust the compass declination on the device and make sure that the sunpath diagram corresponds to the correct range of latitude. If the declination is 12 degrees to the NE, rotate the template counterclockwise 12 degrees (348 degrees). Solar Pathfinder users should consult the manual for more instruction. The location of the Solar Pathfinder measurement is recorded on the site sketchmap.

Although less accurate, smartphone applications can approximate the Solar Pathfinder function. SunSeeker is the best known of these apps and is used by some ecologists. Some surveyors may prefer to use an app due to the convenience and compactness of carrying only a smartphone or tablet rather than the comparatively bulky Solar Pathfinder. Others may prefer the Solar Pathfinder because it does not need to be charged, and for some field crews it may be logistically more feasible to provide a simple, long-lasting piece of field equipment rather than purchasing a more expensive smartphone or expecting crew members to use their personal smartphones. One other consideration is that Springs Online is currently set up to accept Solar Pathfinder data; data from other sources may be in a different format and need to be maintained separately.

Flow Measurement Overview

Systematic hydrogeological measurements are needed for understanding and monitoring springs ecosystems. Modeling of flow variability improves with multidecadal monitoring, so measuring spring flow during each site visit is important. Most hydrogeologists are familiar with Meinzer's ranking scheme for springs discharge rates (1923), but we find that scheme unintuitive because it inversely relates rank to discharge; it also fails to capture the full range of springs discharges. The scale presented in Springer et al. (2008), augmented slightly below, is more suited to ranking springs discharge rates. It uses a logarithmic SI scale and describes the full range of springs discharge rates (Table 4).

When to Measure Flow: Understanding flow variability is important in many situations and flow can be expected to vary seasonally at springs associated with shallow aquifers and low residence-time aquifers. The most conservative flow measurements are made in settings and/or seasons where transpiration losses and precipitation contributions are minimal (e.g., winter, in bedrock emergence settings). However, it is equally important to understand the effects of riparian vegetation and groundwater withdrawal on springs discharge during the growing season, so mid-summer or dry season measurements are relevant as well. In short, there is no single time of year that is best for flow measurement.

Where to Measure Flow: 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. In some cases, the hydrogeologist may choose to measure flow in more than one location, such as sites where the flow is divided into two springbrooks. In such a case, the flow rates calculated from the two measurements would be added together to provide a full estimate of spring flow at the site. The location(s) of where flow was measured should be recorded on the sketchmap, photographed, and described on the field sheet.

Flow Measurement Techniques

General: There are several techniques available for measuring springs flow (Table 4). The hydrogeologist will consider the volume of flow, the site geomorphology, and the available equipment when selecting a flow measurement technique. If available, Level 1 inventory data will inform the team hydrogeologist as to what equipment is needed for flow measurement at a given site.

Most field methods of measuring spring discharge are somewhat imprecise, so it is a good practice to repeat a measurement several times at a single visit. With the methods described below, we recommend making at least six measurements and calculating the average value. To reduce the potential for error, we recommend completing these calculations after returning to the lab. If the discharge of the spring is low (first discharge magnitude; see Table 4), the discharge measurement may take a long time and should be initiated early in the site visit. Second to fifth discharge magnitudes are relatively faster and easier to measure. Measurement of sixth or higher discharge magnitudes using a current meter may take as long as or longer than first discharge magnitude measurements. The hydrogeologist should record the name, serial number (if available), and accuracy of the instrument(s) used to measure flow, as well as indications of recent high flows (e.g., high water marks or oriented vegetation or debris on or above the channel or floodplain).

Below we describe several methods to measure springs flow, beginning with methods suitable for relatively low discharge springs, progressing to methods suitable for springs with higher discharge, and ending with several methods which produce imprecise results but might be used a last resort in difficult situations.

If less than 100% of the discharge is captured by a flow measurement technique, the hydrogeologist should estimate and record the percent of flow captured for each measurement. Flow measurement setups should always be photographed for future reference.

Several of the flow measurement techniques require the hydrogeologist to dig into the stream channel in order to build a small dam or partly bury the flow measurement equipment. Always disassemble dams and fill holes after the flow measurement is complete. Show respect for the springs ecosystem and its future visitors by leaving the site in good condition.

Timed Flow Capture (Volumetric): Volumetric measurements are typically used at springs with first to third discharge magnitude (Table 4), where flow can easily be focused into a volumetric container. This is a straightforward and quite accurate method of estimating discharge rates, particularly if all the flow is successfully captured and the measurement is repeated several times. Unlike using a weir, flume, or current meter, discharge estimates based on volumetric measurements are based on a model of stream stage in relation to discharge. Rather, the hydrogeologist measures volume of water and time, and then directly calculates the discharge. Accuracy depends on the calibration of the container used and the observer's estimation of the percent of spring flow captured. For consistency, discharge should be entered into Springs Online in liters per second.

Table 4. 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, float velocity, static head change
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

Fig. 40. Surveyors measure spring discharge by creating a dam out of soil or, in this case cow feces, to direct the flow through a pipe. This allows the crew to measure volume captured over time.

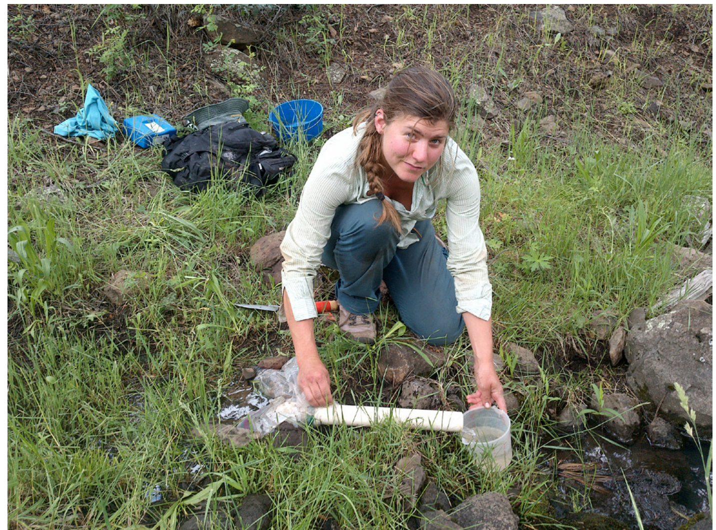


Fig. 41. This surveyor diverted flow into a pipe using a large zip-loc bag.

Start by constructing a temporary earthen or plumber's putty dam to divert water through a pipe of appropriate size for the amount of springs discharge and size of the springbrook channel (Fig. 40). The pipe should be level, not angled up or down. It is often helpful to place a heavy rock on top of the pipe to hold it in place. After the pipe is installed, allow some time for the flow rate to stabilize before taking measurements. This is necessary because digging in the channel to install the pipe inevitably results in new depressions upstream of the pipe. As these depressions fill with water, the flow rate through the pipe temporarily decreases. Once the flow rate has stabilized, place a volumetric container under the pipe to catch the springs discharge. Record the time needed to fill the container, along with the volume of water in the container. Repeat the measurement six times and calculate the mean discharge in liters per second. Photograph the pipe, dam, and volumetric container setup before disassembling it. Be sure to disassemble the dam before leaving the site.

The hydrogeologist should carry several pipes and calibrated containers of various sizes to suit the variety of springs discharge rates expected in the landscape. At smaller springs it may not be feasible to install a pipe, but alternative, more compact equipment can be used. For example, a sturdy gallon- or quart-sized zip-top plastic bag can be used in place of a pipe to focus the flow into a small measuring cup or even into a second plastic bag (Fig. 41). Flow at hanging gardens often is challenging to measure, but sometimes a tarp can be used to capture flow from a dripping geologic contact and divert it into a container for measurement (Fig. 42).

Fig. 42. 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.

Fig. 43. This V-notch weir plate has a 45 degree angle. To use it, drive it into the channel bed so that the flow passes through the V-notch and the marks indicating water depth are on the upstream side. The bottom point of the V-notch should be even with the stream bed, and the plate should be plumb and level.

Portable weir plate: Weir plates are used to measure discharge in spring channels that have low to moderate (second to fourth) discharge magnitudes (Table 4). Weir plates are easiest to use when the channel substrate is relatively fine-grained, so that the weir can be pushed deeply enough into the channel.

To measure flow using a portable weir, push the weir into the stream channel so that all the flow is diverted through the weir's V-shaped notch and the bottom of the notch is level with the stream bed (Fig. 43). Make sure the marks indicating stream stage (i.e., water depth) are on the upstream surface of the weir. Make sure the weir plate is plumb and level, and wait for the water level in the upstream stilling pool to stabilize. Once the water level is stable, record the water depth on the upstream side of the weir. This measurement is also called the "static head." Take this reading and record the measurement six times. The water depth passing though the weir's V-notch should be at least 0.2 ft, or 6 cm; at lower levels, it is not possible to accurately estimate the flow rate. Be sure to record appropriate information on the geometry of the V-notch, which should be printed directly on the weir plate.

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 weir's V-notch. If all the flow cannot be diverted through the notch, be sure to write down the estimate of what percent of flow is captured through the weir. In all cases, it is important to photograph the weir setup (Fig. 44).

Portable weir plates are constructed with different V angles (e.g., 45, 60, 90 degrees). The angle of the V is a variable in the equation that is used to convert water depth (static head) to springs flow rate (US Bureau of Reclamation 1997). There are conversion tables available online that provide discharge rate estimates based on the water depth and the angle of the V-notch. Or use the following equations:

$Q = 4.28C^{*}\tan(\theta/2)(H+k)^{5/2}$

where:

Q = discharge (cubic ft/sec),
C = discharge coefficient (see equation below),
θ = notch angle (degrees),
H = head (ft),
k = head correction factor (ft; see equation below);

and where:

Fig. 44. A surveyor uses a V-notch weir plate (the red device) to measure low volume flows in soft substrate. Note that the surveyor is leaning on a flume, which is not in use.

Fig. 45. A cutthroat flume is useful in low-gradient, relatively fine-grained channels. Although "portable", it is heavy and awkward for use in remote sites. This flume was used to measure flow at a rheocrene spring in Canada.

C = 0.607165052- 0.000874466963*θ + 6.10393334* 10^-6 * θ^2

and:

k = 0.0144902648 - 0.00033955535*θ + 3.29819003*10^-6 *θ^2 - 1.06215442*10^-8 *θ^3.

As Springs Online accepts discharge measurements in liters per second, multiply the discharge rate (cubic ft/sec) by 28.32 to convert to liters per second (L/sec).

Portable Cutthroat Flume: Flumes are most suitable for third to fifth magnitude discharge springs (Table 4) and work best in low gradient channels with fine-grained bed material.

Set the flume in the channel with the wing walls pointed upstream in such a fashion as to focus as much flow as possible through the flume opening (Fig. 45). Make sure the water flows freely out of the downstream end of the flume. Use a bubble level on the floor of the upstream section to make sure the flume is level both longitudinally and transversely. Allow time for the flow to stabilize and then record the water level six times. The exact location on the flume where water depth should be measured varies according to the specific type of flume; the hydrogeologist should look this up before leaving for the field. In many cases, the measurement location will be marked on the flume.

As with the other methods of measuring stream flow, it is important to photograph the measurement setup and record the estimate of percent of spring flow captured by the flume.

The equation used to convert water depth (head) to discharge will vary based on the size of the flume. The below equations apply to the most common sizes of cutthroat flume:

Fig. 46. The channel cross-section with current meter approach is appropriate for discharge measurement in higher volume, wadeable streams.

18” long with 1” wide opening: Q = 0.494H2.15
18” long with 2” wide opening: Q = 0.947H2.15
18” long with 4” wide opening: Q= 1.975H2.15
36” long with 2” wide opening: Q= 0.719H1.84
36” long with 4” wide opening: Q= 1.459H1.84

where

Q = discharge (cfs), and H = head (ft)

Multiply the discharge rate (cubic ft per second) by 28.32 to calculate the discharge rate in liters per second.

Channel cross-section with current meter: Current meters are used for measuring flow in wadable springbrooks where flow cannot be routed into a pipe, weir, or flume (Wilde 2008; Fig. 46). The current meter measures stream velocity, which is multiplied by an estimate of the stream’s cross-sectional area to calculate the discharge rate. Because this method requires surveyors to wade across the springbrook, it is necessary to keep safety concerns in mind. Surveyors should not wade too deeply into water and should not use hip waders in swift water without the use of a safety rope, life jacket, and other appropriate safety gear.

The surveyors should select a measurement location in a straight reach where the streambed is free of large rocks, weeds, and protruding obstructions that create turbulence. The location should have a flat streambed profile. Within the selected reach, establish a channel cross-section by stretching a tag line (we recommend using a measuring tape) tightly across the channel perpendicular to the direction of flow and anchoring it on each side.

Next, the surveyors should decide how to divide the channel cross-section into subsections. The simplest method is to use evenly spaced increments. For example, a 20 m-wide channel may be divided into 20 subsections, each 1 m wide.

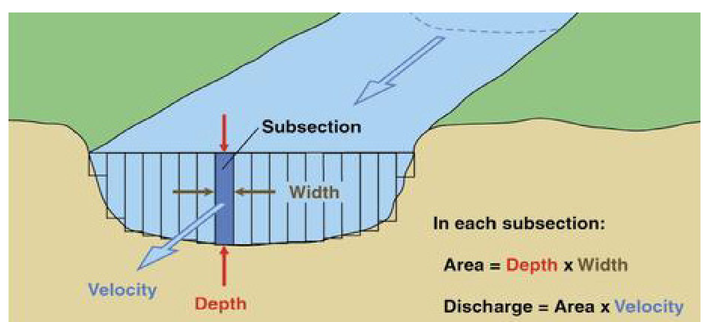


Fig. 47. This channel cross-section is divided into 18 subsections of equal width. When using a current meter to estimate stream discharge, the hydrogeologist measures the average stream depth and velocity within each subsection and uses that information to calculate the stream discharge rate for the entire cross-section. Public domain image courtesy of USGS.

Visualize each subsection as a rectangle and the entire channel cross-section as a row of rectangles standing vertically and stretching across the channel (Fig. 47). This is important for understanding how the velocity calculation works. The hydrogeologist records data at each of the subsections and uses that data to calculate the amount of flow passing through each subsection. Then the hydrogeologist adds together the flow rates from all the subsections to calculate the total flow rate of the springbrook.

To collect the data, the hydrogeologist wades across the stream along the tag line, being sure to stand downstream of the tag line and face upstream when taking measurements. Record the following data at each boundary between subsections:

- X, the distance to a reference point on the bank along the tag line.
- Y, the water depth. Remember to stand downstream of the wading rod or whatever tool you use to measure water depth.
- Stream velocity as indicated by the current meter. Measure the velocity at 60% of the stream depth from the water surface to the channel floor. In other words, place the current meter a little below halfway down to the channel floor when taking the velocity measurement. Remember to stand downstream from the velocity meter while taking the measurement so as not to obstruct flow.

In the laboratory, calculate the stream discharge within each subsection as subsection width (x) times depth (y) times velocity. Sum all of the subsection discharge estimates to calculate the total stream discharge at the cross section (Turnipseed and Sauer 2010).

New technology in the form of computer-integrated cross-sectional flow measurement is now available (e.g., SonTek/YSI FlowTracker), 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.

Flow Measurement in Difficult Settings

Float velocity measurement: This flow measurement method can be used for a range of discharge magnitudes, in circumstances when for some reason flow cannot be focused into a pipe, weir or flume. This method is substantially less accurate than the measurement techniques listed above.

Similar to the current meter method, this technique relies on estimating the area of the channel cross-section and the velocity of the water passing through that cross section in order to calculate the stream flow rate. However, for this method, the stream velocity estimate is much less accurate, as it is based on timing a small object (leaf, apple core, etc.) as it floats downstream on the surface of the current. Because water in different parts of the water column flows at different velocities, an accurate estimate of stream discharge would ideally be based on the average of this range of velocities. The float velocity method relies instead on measuring the stream velocity of the water surface.

Begin by selecting a relatively unobstructed reach of straight channel that is long enough for a travel float time of at least 20 sec. At the upstream and downstream ends of the reach, run a measuring tape across the channel. At both locations, record the channel width and measure the water depth at several regularly spaced points along the measuring tape. It is important that the depth measurements are regularly spaced because these measurements will be used to calculate the cross-sectional area of channel. Also measure and record the length of the stream reach, i.e., the distance between the two cross sections.

Now place a float (e.g., a wooden disk or other small object that will float) in the stream channel upstream of the first cross section tape so that it reaches stream velocity before passing across the upstream line. Record the amount of time it takes for the float to pass from the upstream cross section tape to the downstream tape. Also record the position of the float relative to the channel sides. Repeat this procedure at least six times, placing the float at a different location across the channel each time.

Stream discharge is calculated as the average velocity times the stream cross sectional area. To calculate average velocity, divide the length of the reach by the average travel time (in sec), and then multiply that number by 0.85 to adjust for the difference in stream velocity at the water's surface compared the locations deeper in the water column. The result of this calculation is a rough estimate of average stream velocity (e.g., m/sec or ft/sec). Next calculate the area of each stream cross section by multiplying the stream width by the mean of the several depth measurements. Calculate the mean of the two cross sectional areas, producing an average channel cross sectional area.

Fig. 48. This image shows the depression/sump flow estimation technique. In this case, surveyors dug a hole at the source and measured time to refill.

Discharge is calculated by multiplying the average stream velocity by the channel's average cross-sectional area. When data are entered into Springs Online, be sure to convert the result to L/sec.

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. First, excavate a depression within the seepage area. De-water the depression and record the time it takes for the depression to fill again (Fig. 48). Then measure the volume of the depression using a calibrated container or similar method. Repeat the measurement six times and calculate the average rate of seepage filling the depression. This is an indirect, relative procedure, and must be interpreted with care because often a much larger area is seeping than the area where the depression was excavated.

Static head change: Similar to the depression/ sump method, this method can be used when the spring is not visibly flowing. It is most useful for estimating flow in shallow wells or vertical culverts, but can be used in any relatively small pool of standing water.

Place a staff gauge into the pool and secure it so it stays in place. Record the water depth and describe and measure the geometry of the upper portion of the pool (e.g., record the diameter of a vertical culvert and note that it is cylindrical). Rapidly bail water out of the pool, keeping track of the volume of water that is removed. Record the time it takes for the pool to refill to its original depth. 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: At some springs, including many helocrene springs and hanging gardens, surface flow is diffuse and simply cannot be focused and directly measured. In these cases, measurement and photography of the wetted area may be the only option for quantifying the springs flow. Piezometers (shallow wells) are commonly installed into helocrene springs to monitor the water table depth; this is considered a Level 3 monitoring effort.

Visual flow estimation: Site conditions, such as dense vegetation cover, diffuse discharge into a marshy area, and dangerous access sometimes may not allow for direct measurement of springs discharge by the techniques listed above. Although visual estimation is highly imprecise, it may be the only method possible for some springs. This method should be regarded as a last resort and, when used, it should be supported by photographs, water depth measurements, and/or measurement of the area of moisture or inundation as appropriate to the site. In cases such as these, the hydrogeologist should also recommend equipment that future surveyors might bring to achieve a quantitative flow measurement (e.g., a peizometer array).

Other flow measurement comments: The technique of applying salt to a stream and measuring the wave attenuation of specific conductance (Moore 2005) is not recommended due to potential impacts of NaCl and other salts on springs biota.

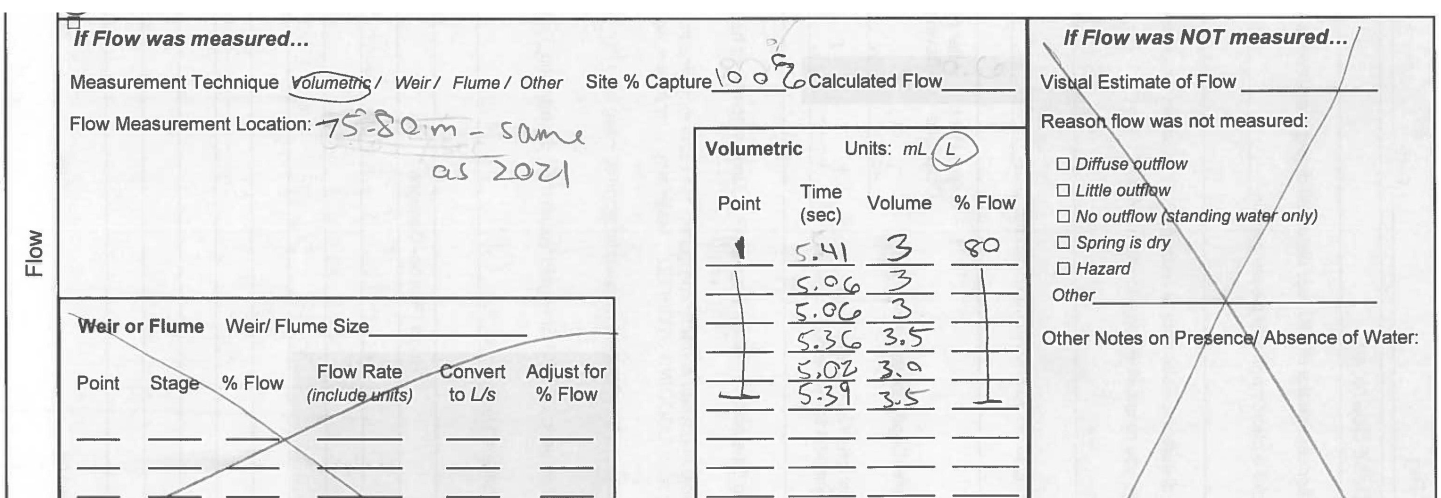
Fig. 49. At Horse Camp Spring in the Gila Wilderness, subaqueous flow emerged into a flowing springbrook, making discharge measurements impossible for a Level 2 survey.

All equipment should be calibrated and checked for consistency. Equations listed are general and may not be accurate for individual weirs or flumes.

Subaqueous springs emerge from the floors of streams, lakes, or the ocean. Difference methods can be used to estimate flow of springs that discharge into flowing streams (i.e., measure streamflow upstream and downstream of the spring source and subtract to determine the spring discharge). 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 (Fig. 49).

Documenting Flow Measurement

For any flow measurement methods, document the raw data on the hydrology sheet in the flow section (Fig. 50).



Flow

If Flow was measured...

Measurement Technique *Volumetric / Weir / Flume / Other* Site % Capture 100% Calculated Flow______

Flow Measurement Location: 75-80 m - same as 2021

Volumetric Units: *mL L*

Point	Time (sec)	Volume	% Flow
1	5.41	3	80
	5.06	3	
	5.06	3	
	5.36	3.5	
	5.02	3.0	
	5.39	3.5	

Weir or Flume Weir/ Flume Size______

Point	Stage	% Flow	Flow Rate *(include units)*	Convert to *L/s*	Adjust for % Flow

If Flow was NOT measured...

Visual Estimate of Flow ______

Reason flow was not measured:

- ☐ *Diffuse outflow*
- ☐ *Little outflow*
- ☐ *No outflow (standing water only)*
- ☐ *Spring is dry*
- ☐ *Hazard*

*Other*______

Other Notes on Presence/ Absence of Water:

Fig. 50. Example of a hydrology fieldsheet with flow measurement data collected using the volumetric method at a relatively small spring. Surveyors measured volume in liters using a calibrated bucket, and measured time required to fill using a stopwatch. They estimated % flow for the entire site as well as for each measurement. With this information, surveyors can enter raw data into Springs Online to calculate the discharge, in this case 0.76 L/sec. Other sections of this fieldsheet are used to enter measurements using a weir or flume, describe the location where surveyors measured flow, and and to document the reason if surveyors did not measure flow.

Field Sheet Page 8: Water Quality

Overview

Spring water geochemistry can add much insight into aquifer mechanics and subterranean groundwater flow path duration. Understanding geochemistry can also shed light on the species assemblages present at a spring, as many endemic invertebrates and rare plants thrive in water or soil with specific geochemical attributes. Some managers may also be interested in spring water chemistry to answer questions about potability, the presence or spread of agricultural or industrial pollutants, and various other basic and applied issues.

For a Level 2 springs inventory, we recommend taking field measurements of several parameters discussed below, using a handheld probe or relatively inexpensive portable kits. However, in many cases, a land manager's specific question may warrant measuring additional field parameters or collecting samples for laboratory analysis. Examples of useful and commonly requested laboratory analyses include tests for anion/cation, isotope, nutrient, and pollutant concentrations. These analyses shed light on the type, flow path, age, palatability (utility), and quality of emerging groundwater.

When measuring spring water geochemistry, the crew hydrogeologist should take measurements and collect samples at the point of emergence to the extent possible. This allows characterization of the supporting aquifer and minimize the influences of atmosphere, soil, and vegetation on geochemistry. Ideally, there will be visibly flowing water at the sampling location, as standing water will likely be altered by atmospheric conditions. At small springs with extremely shallow flows, it is sometimes necessary excavate a small depression near the source in order to submerge a probe deeply enough to take a measurement or to submerge a vial deeply enough to collect a sample. In these cases, the hydrogeologist should wait until the water clears before taking a reading. The location(s) where water chemistry is measured or sampled should be recorded on the site sketchmap and described on the field sheet.

Field measurements

Water chemistry parameters commonly and easily measured in the field are water temperature, pH, specific conductance, total dissolved solids, total alkalinity, and dissolved oxygen concentration. This is an excellent suite of basic parameters to measure for a Level 2 survey. Other water chemistry parameters that might be measured with portable probes include oxidation-reduction potential, salinity, turbidity, nitrate, ammonium, and chloride (Table 5). Although not a water chemistry pa-

Table 5. Chemical parameters commonly measured using laboratory analysis, with labotatory instrument type, detection limit, sample preparation and recommended sample handling times (summarized from Wilde 2008).

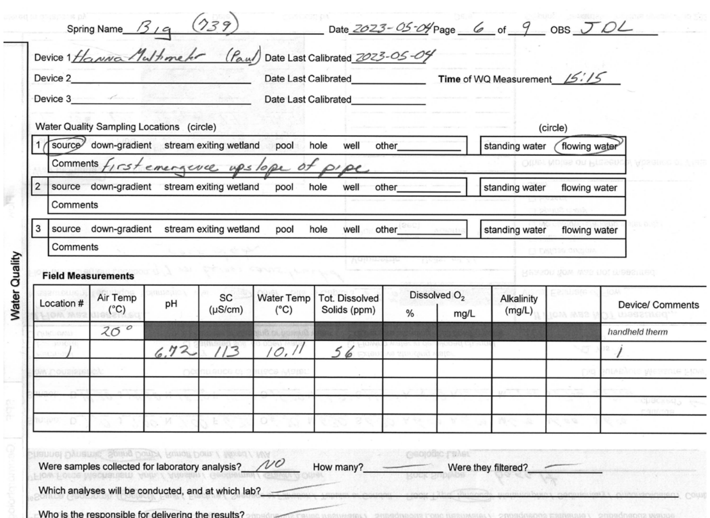
Chemical Parameter	Instrument	Detection Limit	Sample prep	Handling Time
18-Oxygen (^{18}O)			No filtering or preservation required	28 d
2-Hydrogen (^{2}H)			No filtering or preservation required	28 d
Nitrogen – Ammonia (NH_3)	Technicon AutoAnalyzer, or comparable	0.01-2mg/L NH_3^-	Filtered, 4	2 d
Phosphorus (PO_4^{-3})	Technicon AutoAnalyzer, or comparable	0.001-1.0 mg P/L	Filtered, 4	2 d
Nitrate - Nitrite (NO_3^-)	Technicon AutoAnalyzer, 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

Fig. 51. Field test kits are available to measure water quality parameters, such as pH, alkalinity, and dissolved oxygen. These require no calibration, are relatively inexpensive, and provide a useful backup system for electronic units.

rameter, we recommend measuring air temperature at the same time, and include space to record it on the water chemistry field sheet.

Multiparameter probes that measure temperature, pH, specific conductance, and total dissolved solids can be purchased inexpensively (for as little as $150 in 2021). Much more expensive versions are available, of course. But in our experience, the more expensive the sampling device, the more likely it is to malfunction in remote field settings. We recommend carrying at least one inexpensive probe as a backup to use when the primary probe fails.

When in the field, it is important to calibrate probes daily to ensure accuracy of the measurements. Maintain



Spring Name Big (739) Date 2023-05-04 Page 6 of 9 OBS JDL

Water Quality

Device 1 Hanna Multimeter (Paul) Date Last Calibrated 2023-05-04

Device 2 Date Last Calibrated Time of WQ Measurement 15:15

Device 3 Date Last Calibrated

Water Quality Sampling Locations (circle) (circle)

1 source down-gradient stream exiting wetland pool hole well other standing water flowing water

Comments first emergence upslope of pipe

2 source down-gradient stream exiting wetland pool hole well other standing water flowing water

Comments

3 source down-gradient stream exiting wetland pool hole well other standing water flowing water

Comments

Field Measurements

Location #	Air Temp (°C)	pH	SC (µS/cm)	Water Temp (°C)	Tot. Dissolved Solids (ppm)	Dissolved O_2		Alkalinity (mg/L)		Device/ Comments
						%	mg/L			
	20°									handheld therm
1		6.72	113	10.11	56					1

Were samples collected for laboratory analysis? NO How many? Were they filtered?

Which analyses will be conducted, and at which lab?

Who is the responsible for delivering the results?

Fig. 52. Example of the water quality fieldsheet. Note that surveyors can enter more than one location for measurements, and more than one device. This sheet also includes fields to document instrument calibration. Also if samples for collected for analysis, this is documented at the bottom of the sheet.

a calibration logbook. Besides providing documentation of each probe's calibration history, the logbook can be useful in tracking probe malfunctions and deciding when each needs maintenance or repair. Note that daily calibration necessitates bringing standard solutions to the field for each water quality parameter being measured. Inexpensive, reliable field kits are available for measuring some water quality variables, such as dissolved oxygen and alkalinity (Fig. 51).

The water quality fieldsheet is designed to document which devices are used and when they were last calibrated, location of measurements, measurements, and whether or not samples were collected for analysis (Fig. 52).

Laboratory Water Quality Analysis

When collecting water samples for laboratory analysis, work with the lab to clarify the collection requirements for the particular analysis. Table 5 provides some basic guidelines, but we advise working directly with the lab because methods may change over time. Details to clarify prior to beginning field work include:

- What is the required volume of each sample?
- What type of bottle to use, and how should the bottles be prepared (rinsing with HCl and/or DI water)?
- Do they recommend collecting duplicates of some or all samples?
- Will it be necessary to filter the samples in the field? If so, what extra equipment will be needed?
- Is it necessary to wear gloves when collecting the samples?
- What temperature to store the samples, and how quickly do they need to be delivered to the lab?

The answers to the above questions will refine the details of the field sampling plan and necessary preparations; however, the following procedures will be generally applicable when preparing to collect spring water samples for laboratory analysis.

- Assemble enough sample bottles of the correct size. Prepare extra bottles, if possible.
- Wash the bottles per instructions from the laboratory. This will often consist of rinsing them in hydrochloric acid three times, followed by rinsing with deionized water. Be sure to wear gloves and safety glasses when working with hydrochloric acid. Allow the bottles to air dry and then cap them.

- Apply a piece of labeling tape to each bottle. Use distinctive colors of labeling tape to distinguish treatments, if needed.
- Prepare and pack the filtering equipment, if necessary.
- Pack the bottles, along with markers to label the bottles, and extra labeling tape.
- Make preparations to store the samples at the appropriate temperature (bring a quality cooler with enough ice) and have a plan for delivering the samples to the laboratory on time.

Field Sheet Page 9: Spring Ecosystem Assessment Protocol (SEAP)

The SEAP form guides the surveyor through an assessment of the ecological integrity of the spring and includes space for the surveyors to provide management recommendations. The concept behind the SEAP analysis is that the surveyors begin by integrating the information gathered during the ecological inventory with background knowledge about the spring, its land use history, and the surrounding landscape. All of this information is used as context for completing a site assessment, in which the surveyors rank the site's condition and risk levels. This completed assessment is in turn used to draft management recommendations. The SEAP is a quantitative, data-driven approach to ecosystem assessment, which also provides space and flexibility for surveyors to use their own expert knowledge and creativity to draft management recommendations.

The variables considered in the assessment are grouped into these six categories:

- Aquifer and Water Quality
- Site Geomorphology
- Habitat and Microhabitat Array
- Site Biota
- Human Uses and Influences
- Administrative Context

The first four categories describe the condition of the spring's natural resources, and the fifth category accounts for changes due to human activities. The sixth category, Administrative Context, is best evaluated through a discussion with the land or resource manager, focusing on the steward's expectations, desires, and level of satisfaction with the current status of the springs ecosystem.

Within each category, the surveyor ranks the spring's condition and risk based on 5 to 8 variables. The rankings are assigned based on a 0 to 6 scale. For the site condition assessment, a score of 0 indicates extremely poor condition and 6 indicates a pristine condition. For the risk assessment, a score of 0 indicates no risk whatsoever to the springs ecosystem, and 6 indicates extremely high risk (likely unrecoverable conditions) to the springs ecosystem. Risk is interpreted here as the potential threat or the "condition inertia" (the inverse of restoration potential) of the site condition associated with that variable. In other words, what is the probability that variable will remain unchanged? Condition scores below 4 indicate an impaired condition, and risk scores above 2 indicate elevated risk. Field crews completing the SEAP analysis should refer to the SEAP Scoring Criteria (Appendix B), a guide that defines the scoring criteria for each variable.

The SEAP is designed to stimulate discussion and recognition of site issues with the springs steward(s), and has been used successfully in Kaibab and Stanislaus National Forests, in Ash Meadows National Wildlife Refuge, in Alberta (Springer et al. 2015), and elsewhere (Paffett et al. 2018). The SEAP provides technical guidance to the springs steward(s), but is intended to support, not supplant, management planning.

When applied to many sites within a landscape, the SEAP is a powerful tool for comparing springs condition and risk levels, and guiding landscape-level stewardship planning and rehabilitation efforts. For more information on how the SEAP was developed and how it can be used to guide land management planning, refer to the Arizona Springs Restoration Handbook (Stevens et al. 2016).

Sociocultural and Historical Inventory

Springs play important roles in local and regional Indigenous cultural landscapes, in history, and in socioeconomics. 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.

Such information may include a wide array of ethnoenvironmental, economic, religious, historical, and traditional ecological knowledge and data. If deemed appropriate by land managers and tribes, these data may be archived in Springs Online, through written notes added to the site description, by uploading reports and photos, or providing hyperlinks to photographs, videography, and recordings of interviews. Thus, the Springs Online 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.

As surveyors assemble historical and sociocultural information, they also have the option of including it in the SEAP assessment, through scoring in the Human Uses and Influences and Administrative Context categories, as well as incorporating that knowledge into management recommendations. The SEAP Administrative Context category includes the variables Cultural Value, Indigenous Significance, and Historical Significance. There is a dedicated "Comments" field associated with each of those variables, where stewards can add additional information. The SEAP Scoring Criteria document (Appendix C) also includes a seventh category, "Cultural Values," with 10 assessment variables. Field crews and spring stewards concerned with the cultural or historical value of a spring have the option to include this section in their SEAP analysis. Because of tribal data confidentiality concerns, this section is not currently included on the SEAP Field Sheet, nor is it included in the Springs Online data entry interface. We encourage indigenous stewards to compile these data and retain them for their own records, being sure to include the Springs Online site name and ID number so the data can be reliably associated with the correct spring.

Post-Field Tasks

Data Backup

Losing data by misplacing field sheets, failing to download photos, or inadvertently overwriting GPS data, is one of the most expensive mistakes a springs ecologist can make. Upon return from the field, surveyors should immediately back up all collected data. We recommend developing a checklist of data backup tasks for crews to complete during their first office day after returning from the field. Staff should sign off after completing each task, and the list itself should be archived along with the data. Tasks to be completed might include:

- Scan field sheets. Properly label and save the scans to a designated file on a computer, server, or in the cloud.
- Organize the paper field forms and store them in a designated location.
- Download photos, properly label, and save to a designated location.
- Download GPS waypoints and tracks, properly label, and save to a designated location.
- Download data from any other device that collects and stores data. This might include a current meter or water chemistry probe.

Equipment Maintenance

Equipment and supplies used while conducting field work on dozens of springs over many weeks will undoubtedly require corrective and preventive maintenance. Most field equipment will need to be washed, and some pieces should be sterilized. Sensitive electronic equipment such as GPS units, field computers, satellite phones, and radios need to be properly stored in accordance with manufacturer instructions. This may include removal of batteries, or in some cases storage with a fully charged battery.

Water quality probes should be cleaned and stored according to manufacturer instructions. Thoroughly cleaning probes between field trips is advisable, because mud-caked sensors will not produce accurate readings (Fig. 53). Many types of water chemistry sensors should not be allowed to dry completely, and most need to be stored in a special solution; consult the owner's manual for your probe. This is also a good time to check the calibration log and determine which probes have been malfunctioning and may need their sensors replaced.

Nets used to collect invertebrates should be sterilized between uses to prevent spreading diseases and invasive species.

Note supplies that are running low (e.g., pencils, markers, water chemistry probe calibration solutions, invertebrate sample vials) and order replacements.

Fig. 53. Water quality probes should be examined after returning from the field and cleaned. Soak them in cleaning solution and rinse thoroughly. Store the probes in an appropriate storage solution.

Vehicles sustain damage and wear from transporting the survey team on rough roads and across sometimes vast landscapes during springs inventories. Because of the varied and often harsh conditions to which vehicles are subjected, preventive and corrective maintenance should be a high priority. This entails regular oil and filter changes, checking tire tread wear, thorough cleaning of undercarriage and engine compartment, and general cleanliness of the cab and truck bed.

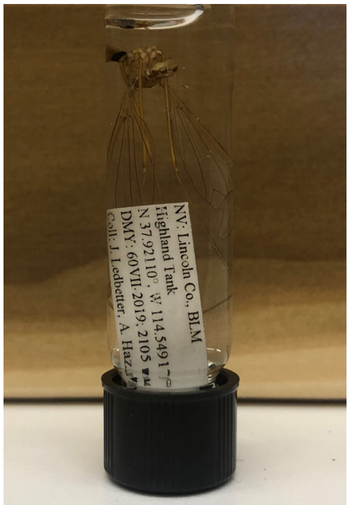


Fig. 54. Collected soft-bodied specimens are labeled, preserved in ethanol, and stored in a laboratory setting.

Specimen Management

Biological specimens require preparation, taxonomic identification, and databasing. Quality specimens should be curated and archived in a professional museum collection.

Invertebrate Specimens

Soft-bodied aquatic macroinvertebrate preparation: Samples of soft-bodied invertebrates brought in from the field are generally mixed collections preserved in ethanol and containing multiple specimens from a particular site or quantitative sample replicates. These samples will inevitably contain debris such as pebbles and leaf litter. Laboratory staff will first separate the invertebrate specimens from debris, and then sort the specimens at least by morphotaxon. For normal operations, each morphotaxon will be transferred into its own vial in 70% ethanol with a provisional label with the collection date, collection site name, and taxonomic order (Fig. 54).

If the sample was obtained using a quantitative sampling technique, the staff member will enumerate the individuals in each morphotaxon. This will allow calculation of standardized density (the number of individuals per unit area per minute of sampling).

Fig. 55. Collected hard-bodied invertebrates are pinned, labeled, and stored in a laboratory setting.

Hard-bodied invertebrate preparation: Samples of hard-bodied invertebrates will usually be stored in acetate envelopes when brought in from the field. If the sample is mixed, it will first be necessary to sort the sample according to morphotaxa. After sorting, pin the specimens. Consult Triplehorn and Johnson (2005) or other entomological texts for detailed mounting and pinning instructions (see also Fig. 21). Nearly all hard-bodied invertebrate specimens should be pinned; the exceptions to this rule are adult dragonflies and damselflies, which are permanently stored in clear envelopes because they are exceedingly delicate. All specimens, pinned or otherwise, should be accompanied by provisional labels with the collection date, collection site name, and taxonomic order of the specimen, prior to application of formal institutional labels (Fig. 55).

Identification and Curation: Sorted, provisionally labeled invertebrates should be 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, and others).

For some groups of invertebrates, expert entomological taxonomy is required for specimen preparation and identification. For example, the mandibles of cicindeline tiger beetles should be spread for ease of identification. Genetalic dissections often are needed for species-level identifications. In some cases, specimens will need to be sent to experts for identification.

Final specimen labels should be typed and printed in 4-point font on heavy-stock, white, acid-free paper. Labels should be no larger than 6 by 15 mm in size. Each specimen receives two labels—a locality label and a taxonomic label. Pin labels neatly below the macroinvertebrates for pinned or pointed specimens, or place them inside the vials of alcohol-preserved specimens. We prefer the following left-justified format for specimen locality labels:

3-letter country code. State or Province 2-letter code:
County or similar level code; Land Management Unit
Site Name (Site number, if any)
Latitude, Longitude in decimal degrees
Date: Day-Month-Year; elevation (m)
Collector(s)

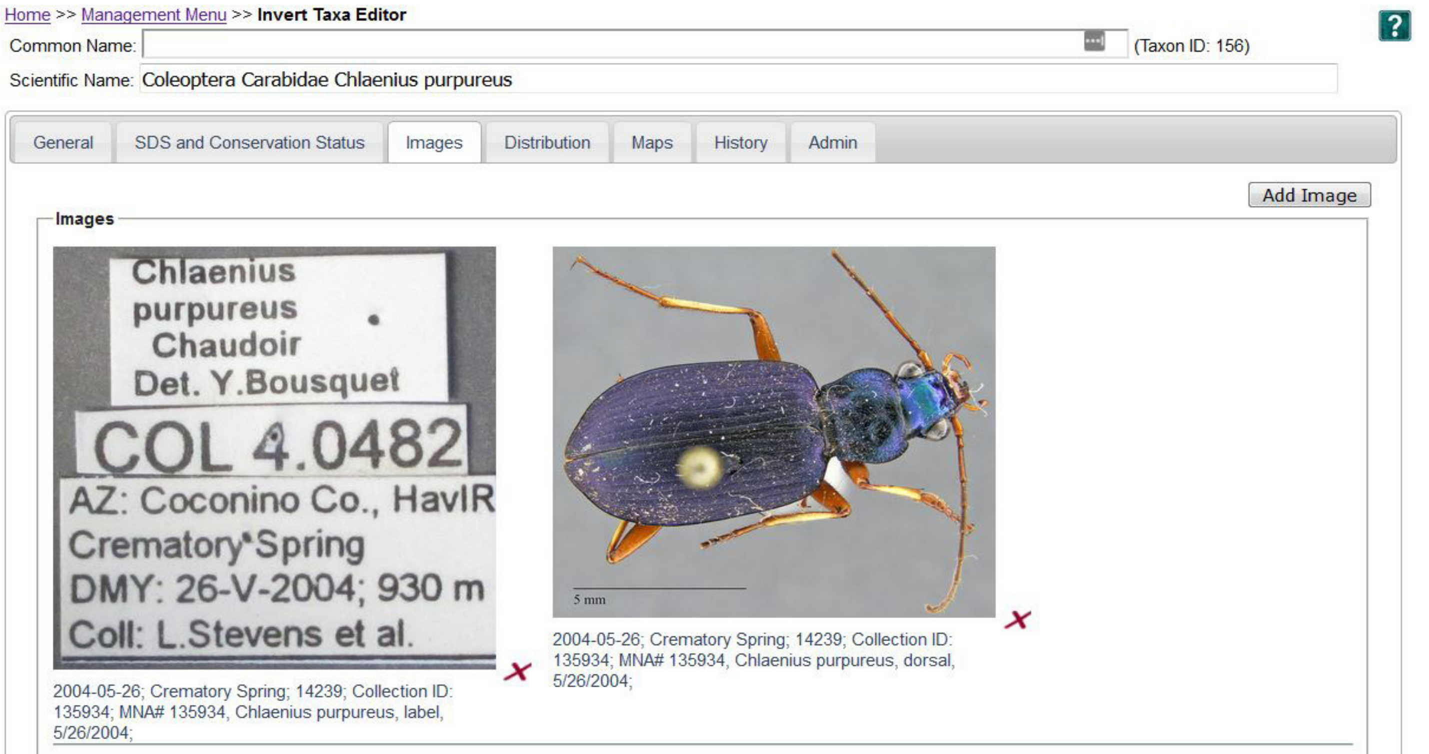


Fig. 56. In Springs Online, photos of plants and animals can be uploaded and associated with a taxonomic record as well as a specific springs survey. As a relational database, Springs Online provides a framework to address and analyze ecological complexity.

Final taxonomic labels are pinned beneath the locality label. We prefer the following centered format:

Genus species subspecies
Author and year (with or without parentheses, as appropriate)
Det: (the taxonomist) Year of ID

Invertebrate specimens may be retained in-office, in a secure, dark, cool environment and used to create a reference collection for the land management unit, or they may be added to a museum collection. Remember to incorporate the final taxonomic identification of each specimen into the springs inventory dataset, including the original field sheets as well as Springs Online (Fig. 56).

Botanical Specimens

In Level 2 inventories, plant specimens collected for identification or to serve as vouchers should be dried in a plant press. Each specimen should be labeled with the site name, date, microhabitat, and collection number or code name for the plant that the botanist used on the field sheet (Fig. 35).

Identify plant specimens to the lowest taxonomic level possible using local or regional floras and field guides. SEINet (swbiodiversity.org) is valuable resource for plant identification in the southwestern United States, and contains links on its homepage to affiliated websites in other geographic regions. It is often advisable to visit a local herbarium for a variety of plant identification resources, including the most recent floristic treatments and the opportunity to closely examine specimens from the collection (Fig. 57).

Incorporate the final taxonomic identifications into the springs inventory dataset as soon as possible. While it is possible to revise data in Springs Online any time, it is simplest and most efficient to identify plants and revise the field sheets with the identified plant name before the data are entered.

Good quality specimens should be retained as herbarium specimens, especially if they document uncommon taxa or range extensions. Work with your local herbarium to determine whether they are interested in accepting your specimens and how they

Fig. 57. erbarium specimen of *Geranium richardsonii,* from the Museum of Northern Arizona's collection.

prefer specimens be submitted. Some herbaria prefer that contributors create their own labels using a specific format, and others prefer that their own staff complete that task. Alternately, plant specimens may be retained in-office, in a secure, dark, cool, insect-proof cabinet and used to create a reference collection for the land management unit. Refer to Bridson and Forman (1998) for guidance on preparing and preserving herbarium specimens.

Level 3 Inventory

Overview

Level 3 springs work includes any stewardship activity that seeks more detailed or in-depth information than a single Level 2 Inventory provides. This might include monitoring, research, rehabilitation planning and implementation, or development. While Level 1 and Level 2 inventory efforts are sometimes motivated by very general research questions, such as the simple desire to understand how many springs exist in a landscape, what types of ecosystems they support, or their ecological integrity, a Level 3 effort is context-specific and driven by focused stewardship questions. Because Level 3 efforts are context-specific, we do not attempt to prescribe protocols here. Rather, we direct the reader to synopses of basic and applied research conducted at Silver Springs in Florida (e.g., Kemp and Boynton 2004), Montezuma Well in Arizona (Blinn 2008), and Yellowstone Hot Springs in Wyoming (Brock 1994), where detailed Level 3 studies have been undertaken. Many Level 3 efforts include long-term monitoring, so we also present a general discussion about setting up a long-term springs monitoring program, followed by common techniques that might be employed for detailed research or monitoring of each of the physical and biological parameters included in the Level 2 Inventory.

Stewards interested in restoring or rehabilitating springs may review the Arizona Springs Restoration Handbook (Stevens et al. 2016) for guidance pertinent to the arid and semi-arid American West. Stewards embarking on springs development projects will find useful guidance in Rangeland Water Developments at Springs: Best Practices for Design, Rehabilitation, and Restoration (Gurrieri 2020).

Monitoring

Monitoring is the scientific acquisition, analysis, and application of data to inform stewards about system changes or responses to treatments over time and to improve resource stewardship. Monitoring is best conducted in relation to clearly defined goals, objectives, and scientific questions. 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, field methods, and information management of the program prior to initiation. Managers should keep in mind that the cost will include not only expenses associated with field work, but also the time needed to compile, summarize, archive, and interpret the data.

In general, 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 is needed to ensure that the stewardship team understands management success and challenges—whether the goal is conservation of a particular resource, a sole-site restoration action, or a more broadly applied action or policy. Monitoring provides the scientific information for focused discussion about improving stewardship: monitoring plans should be tailored to help stewards understand trends in springs ecosystems and clarify the next steps towards improving stewardship. However, monitoring should not be used an excuse for inaction or delayed response.

Prior to beginning springs ecosystem monitoring, it is important to develop and refine the statistical framework for answering the management questions. This will include identifying the variables to be measured and the frequency of sampling; this process is necessary to ensure that the monitoring data will be sufficient to answer the manager's questions. If a large monitoring program is proposed, we strongly recommend consultation with a professional statistician to ensure the cost-efficiency of the project and the scientific credibility of the results.

What to Monitor

Selecting variables: 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 Stevens et al. 2021), cultural and economic values, and ecological integrity. Completing Level 2 inventories of springs is an excellent way to establish monitoring or other management activities priorities, as well as determine which attributes of the springs ecosystem require monitoring (Paffett et al. 2018). Springs that are prioritized for rehabilitation particularly warrant comprehensive pre-treatment baseline and post-treatment monitoring (Davis et al. 2011).

SSI Level 2 Protocol as a Monitoring Program: A simple monitoring program might consist of repeating the Springs Stewardship Institute's Level 2 Inventory Protocol and SEAP at regular intervals (e.g., annually, or every few years). If this approach is taken, it will still be advisable to take extra precautions (beyond those described in the Level 2 Protocol) to ensure the repeatability of each measurement technique chosen. For example, the monitoring plan might include repeated flow and water quality measurements in accordance with the SSI Level 2 Protocol, with the goal of detecting trends over time. In this case, it may be advisable for surveyors during the first monitoring visit to carefully document the precise location of each of these measurements (using photography, a written description, emplacement of stakes, and delineation on the site sketchmap). Future surveyors should bring this documentation into the field and take measurements in the same locations. Depending on the goal of the monitoring plan surveyors might need to conduct monitoring during the same week of each year.

While the SSI Level 2 Inventory Protocol provides an excellent framework for quantifying springs physical and biological integrity and function and the extent of human impacts, the protocol may or may not be sufficient for a Level 3 monitoring program. As a rapid assessment method, the Level 2 Protocol excels at breath rather than depth. Managers should be certain they have clearly defined the questions they seek to answer before embarking on a monitoring project. Specific goals, such as development of a high-precision landscape base map, construction of a groundwater model, using transects to monitor vegetation change, or determining population trends of rare species may not be effectively addressed using SSI's Level 2 Protocol.

When to Monitor

The seasonal timing and frequency of monitoring should be informed by the monitoring goals and research questions, and the project budget also must be considered. As discussed in the "Field Work Planning" section, there is no single ideal season for characterizing all springs variables of interest. Depending on the specificity of the monitoring goals, it may be necessary to monitor more than once per year; for example, some hydrologic questions may necessitate frequent site visits or automated continuous data collection, and compiling a complete floristic inventory will necessitate several visits throughout one or more growing seasons. Documenting long term trends in most hydrologic or biological variables will generally require repeated visits during the same season, or even the same week of each year, in order to minimize seasonality-driven variance in the dataset.

Monitoring Plan Elements

Overview: Here we review common research questions and monitoring goals for several frequently measured physical and biological variables. We describe some methods that may be suitable for answering these questions, but we do not repeat the standard methods and guidance from the Level 2 Protocol. Managers designing springs monitoring programs should familiarize themselves with the basic inventory techniques described in the Level 2 Protocol before proceeding to the more advanced techniques mentioned below.

Site Map: Many monitoring programs, particularly those associated with springs restoration, rehabilitation, or other such treatments, will benefit from the development of a high-precision, fine resolution map of the springs ecosystem. A high-quality map of the study site allows documentation of treatment locations (e.g., where willows were planted, excavation was performed, or fences were built) and sampling locations, as well as the ability to spatially track changes in geomorphology, vegetation cover, or survival of planted vegetation. Such a map can be developed from aerial photography at 0.3 m or finer scale, or carefully sketched on graph paper using a plane table and measuring tapes. See the Level 2 Inventory Protocol for additional guidance on drawing effective sketchmaps. When a springs monitoring program requires that samples or measurements be taken in the same location each time, the detailed map will be instrumental in re-locating these sampling locations.

Photography: Springs monitoring programs all benefit from repeat photography. Even if the photographs will not be formally analyzed for changes, they are invaluable for adding context to other data collected in the monitoring program. Furthermore, they are useful for reporting (Fig. 58). Webb et al. (2010) examined repeat photography methods in detail, but we find that the following basic tips generally suffice for repeat photography at springs:

- Select vantages that include multiple permanent or semi-permanent "hard points," such as distinctive boulders or rock formations. When possible, incorporate the skyline into the photos. When no true "hard point" is available, include large fallen logs, or unusually shaped trees.
- Keep a photo log and describe in detail the location where each photograph was taken, and which direction the photographer faced. Also write the subject of the photo and describe the hard points. An example of a photo log entry might be "Standing 10 m directly downslope of the cave entrance, facing NE. Cave entrance at photo left, 1 m-tall triangular boulder at photo right, on left bank of springbrook."
- Take at least two photos of each vantage, in case one is blurry.
- Mark photo points on the site map, with an arrow indicating the direction the photographer faced.

Fig. 58. Example of repeat photography from 2020 and 2021 surveys at Banfield Spring in Coconino National Forest, Arizona.

- If the photo point is far from the spring source (such as the top an adjacent ridge) or the site is extremely large, it may be appropriate to record GPS coordinates of the photo point. However, this should not replace the detailed written description of the photo point and marking the location on the site map.
- On return monitoring visits, surveyors should bring copies of the photos along with the photo log and sketchmap. With these resources, they will be able to be sure they are re-occupying each photo vantage.
- Surveyors may choose to install stakes to mark the photo points. Before doing so, surveyors should consider factors that might lead to loss of the stakes, such as the intensity and type of land use at the site and other likely disturbances, such as flooding. Because stakes are prone to loss or burial, they should not replace a detailed written description of the photo point and marking the location on the site map.

Geomorphology Monitoring: Monitoring programs associated with springs restoration or rehabilitation projects will likely include 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.

A carefully prepared site map will allow surveyors to track geomorphic changes if microhabitats are relocated during each site visit and the area of each is measured and re-drawn on the 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. These variables can clarify trends in other physical and biological characteristics through time at the springs ecosystem.

More sophisticated methods of geomorphological monitoring include spatial analysis of aerial (e.g., Google Earth or drone photos; Fig. 59) or oblique photographs using a computer program such as ArcGIS, or using advanced machine learning algorithms (e.g., Khan et al. 2020). If oblique photographs are used, the site photographs should be taken 45-60° apart at approximately the same elevation to ensure to adequate three-dimensional representation of the site.

Flow Measurement: One of the simplest springs monitoring questions regularly asked is "How often does this spring flow?" For perennial springs, managers might ask "Is the flow at this spring increasing or decreasing?" or "Is the flow at this spring sufficient to support my proposed land use?" or "Will nearby groundwater pumping decrease the flow rate at this spring?" Questions related to springs discharge rates can sometimes be answered with periodic in-person discharge measurements, using methods described in the Level 2 Inventory Protocol. If this course of action is taken, surveyors should standardize the location, season and method used to minimize variation in measurements.

If more data are needed than are provided by in-person visits, stewards should consider instrumenting the spring with devices that collect continuous data. Ephemeral springs can be instrumented with Hobo Tidbits or similar devices which detect presence or absence of water. At helocrene (wet meadow) springs lacking channelized outflow, surveyors can install piezometers (shallow wells for measuring depth to groundwater) with pressure transducers that record depth to water at closely spaced intervals (e.g., hourly or every 15 min; Fig. 60). Several discharge measurement options exist at springs with channelized outflow, including installation of a weir or flume with a datalogger. At any spring type, game cameras, set to take photos daily, can be utilized to monitor stream stage or pool depth.

Answering some questions, including those related to climate change predictions, may necessitate the development of a groundwater model, a project for a professional hydrologist. This is a generally costly task that requires considerable knowledge of geologic stratigraphy and structure, climate, geochemistry, and long-term springs discharge and nearby well data, and typically involves at least a year or more to develop and test.

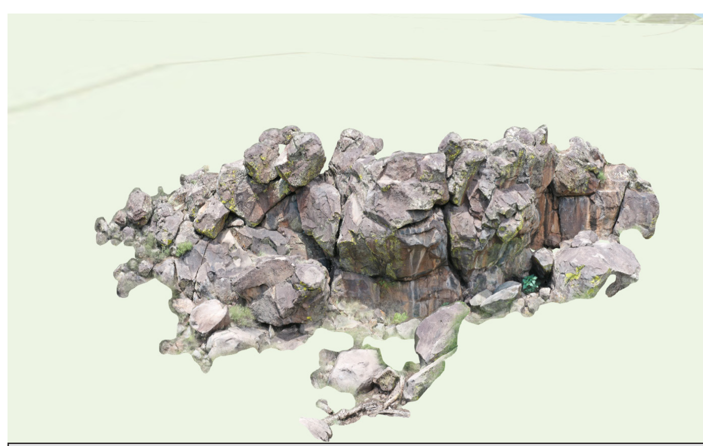


Fig. 59. Example of 3-dimensional drone imagery, taken by SSI GIS Analyst Jeff Jenness, at Picture Canyon in northern Arizona. It is possible tour a high-resolution version of this model at https://tinyurl.com/yh9papmu

Fig. 60. A piezometer installed on creek right at Blue Headwater Spring in Cibola National Forest, New Mexico.

While beyond the scope of this discussion, Anderson et al. (2015) provides a comprehensive description of the fundamentals of groundwater modeling.

Water Quality Monitoring: Common monitoring questions related to springs water quality include tracking the spread of pollutants or otherwise tracking the effect of adjacent land use on springs water quality. For example, a springs ecosystem near a major highway might reveal annually increasing salinity due to winter application of de-icing salt to the road. While surveyors may notice trees dying near the spring, they can better document this relationship by monitoring the geochemistry of the springs water.

If a monitoring program includes repeat measurements of certain water chemistry parameters, surveyors should standardize the location and season of the measurements, as well as the type of equipment used, in order to make sure any trends detected cannot be attributed to those factors. Monitoring programs that include repeated water quality measurements should also require a flow measurement each time a water quality measurement is taken. This is because discharge is often a covariate affecting water quality, with an inverse relationship between discharge and ion concentration (as is said, "dilution is the solution to pollution").

Vegetation: Common monitoring goals related to vegetation include completing a floristic inventory of the site (i.e., compiling a plant species list as completely as possible), documenting the population trend for a target species, or monitoring changes in the plant community, particularly after some rehabilitation action has been completed, such as invasive plant removal or site revegetation.

Completing a floristic inventory necessitates several visits to the spring during different seasons of the year, with more frequent visits during the most productive seasons. Traditionally, this is done for at least two consecutive years because many annual plant species will not emerge each year, nor will many perennial species that die back to the ground when dormant. Surveyors should create voucher specimens for all but the most common species and deposit the vouchers in a local herbarium or retain them in a working collection associated with the land management unit. It is also an option to collect duplicate specimens and do both.

The SSI Level 2 vegetation methods, repeated annually or seasonally, may be used to document broad changes in vegetation through time. For example, the Level 2 vegetation protocol may be sufficient for monitoring vegetation changes following invasive plant removal. In this case, the monitoring goals might be to determine whether the invasive species has returned to the site and to document which native species have taken its place.

If the monitoring goal is to document the population trend of a sensitive species, particularly with the goal of determining population viability, or if the monitoring program needs to detect minor shifts in vegetation in a statistically rigorous way, stewards will need a more intensive sampling design, which likely will include establishing quadrats or transects. Measuring and Monitoring Plant Populations (Elzinga 1998) is an excellent resource, freely available online, that covers all aspects of plant monitoring from setting monitoring priorities; deciding what parameters to measure and the best the size, shape, and number of sampling units for a monitoring program, to statistical analysis and interpretation of results. The primary focus of the book is on monitoring the population status of rare or special status plants, but much of the information is directly transferrable to community-level vegetation monitoring. Any steward designing a vegetation monitoring program should own and use this resource. The New Zealand Department of Conservation has also developed a useful resource on vegetation monitoring (Rose 2012), which focuses more on monitoring the vegetation community and includes decision trees to help the steward decide on the most suitable monitoring technique to meet a monitoring program's goals.

In habitats subject to flood disturbance, including rheocrene and even some gushet and hanging garden springs, vegetation cover can be exceptionally dynamic. For example, Grand Canyon Wildlands Council (2004) reported that wetland vegetation cover varied from 20 - 80% over three years at one gushet spring. Stewards designing vegetation monitoring plans should consider the potential of high variability in cover data from year to year. At such highly dynamic springs, vegetation cover will be difficult to interpret as a monitoring metric. When the monitoring goal is population trend assessment for a sensitive species, stewards will need an exceptionally well-thought-out study design, with serious consideration given to sample size and statistical power.

More specialized vegetation analysis techniques include thin slice analysis of travertine to provide insight into diatom composition in relation to water quality over time, and dendrochronological analysis of trees, for retrospective trend data on tree growth, spring flow rates, and potentially water quality (e.g., Fuchs et al. 2019).

Invertebrates: Monitoring goals related to invertebrates include developing a list of taxa that is as complete as possible, monitoring the population trends of target species, and monitoring trends in the aquatic or wetland/riparian invertebrate assemblage. Invertebrate assemblage monitoring is sometimes done to provide an indication of water quality.

If the goal of the study is to develop a complete list of taxa, qualitative opportunistic (spot) sampling is recommended, as that method allows for sampling the widest variety of habitats. In order to capture the largest diversity of invertebrates, surveyors should conduct intensive opportunistic sampling several times throughout one or more years, during different times of day, and not neglect sampling at night. Surveyors should sample a variety of habitats, including the benthos, throughout the water column, the margins of channels or pools, the surrounding vegetation, and underneath rocks and logs. There is more information about spot sampling techniques in the Level 2 Protocol. Nocturnal ultraviolet light trapping can be used to collect adults of some groups (e.g., caddisflies) that may not otherwise be detected. Malaise and pitfall traps also are useful to supplement spot sampling because they allow insect detection while the zoologist is offsite. Environmental DNA (eDNA) analysis of spring water is a useful technique for revealing the presence of cryptic and aquifer-dwelling species.

The size and/or condition of a target species population may be monitored using the quantitative benthic sampling methods described in the Level 2 Protocol. Other available quantitative sampling methods that are not mentioned in the Level 2 Protocol include timed nocturnal light trapping, Malaise trapping, pitfall trapping, and transect sampling. When selecting a quantitative sampling technique to monitor a target species, the steward should consider the life history and habitat preference of the taxon of interest, as well as the site geomorphology. If the monitoring goal is to document a population trend or construct a population viability model, the steward or zoologist should consult with a statistician to confirm that the proposed sample size and other details of the monitoring plan are sufficient to answer the question. The zoologist should also consider the conservation status and vulnerability of the species or population of interest. For example, Martinez and Thome (2006) used quantitative monitoring to determine population dynamics and the life history of the endemic Page springsnail (*Pyrgulopsis morrison*i) in central Arizona, but reported that sampling without replacement reduced the population size on subsequent visits.

Many of the same quantitative sampling methods recommended in the Level 2 protocols can be used for monitoring population trends in invertebrate assemblages. In all cases, the methods to be used should be selected based on the life histories and habitat preferences of the suite of species of greatest interest, as well as on site geomorphology. A number of useful species composition metrics have been developed to assess water quality (Merritt et al. 2008). Among the more commonly used indices are the EPT index, which is calculated by summing the number of mayfly (Ephemeroptera), stonefly (Plecoptera), and caddisfly (Trichoptera) taxa (EPT) or individuals 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 habitat quality. However, naturally ion-rich waters often are encountered at springs, and such waters commonly and naturally do not support high levels of EPT. In such cases, other invertebrates (particularly rare or endemic taxa) may be better indicators of water quality.

Vertebrates: Common monitoring goals related to vertebrates include developing a list of taxa that is as complete as possible; monitoring the population trend of one or more target species or groups (such as fish or amphibians); and monitoring the health of those populations.

If the monitoring goal is simply to develop a taxon list that is as complete as possible, it may be sufficient to opportunistically record presence, signs, or sounds of vertebrate species detected during repeated monitoring visits. Long-term monitoring using this procedure will eventually build a representative list of vertebrate taxa that use the site. However, to build a list of taxa more quickly and completely, motion-activated cameras, trapping, track plating, and a more intensive site visit schedule can be employed. eDNA analysis of spring water samples can also be useful for revealing the presence of cryptic species. If the goal of the study is population trend detection, it will be necessary to use standardized observations or trapping techniques. As with any biological population or ecological community trend assessment, it is important to consult with a statistician to make sure that the study design is sufficiently rigorous to answer the question.

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 (Nur et al. 1999). Live trap sampling population assessment and disease vector monitoring methods have been developed for small mammals (SERAS 2003). Genetic 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 (Schwartz et al. 2006).

Data Management

Early Planning

One of the earliest steps in any springs stewardship program should be to create a data management plan. Unfortunately, this step is too often neglected until after field data are collected, inevitably leading to inefficiencies and sometimes even to failure in producing a report or analyzing the results.

Stewards should plan and implement a data management system early in a project in order to properly organize and archive the background information that they gather about each spring. Compilation and review of legacy data leads to better understanding of what information is already available. Without such a system, these background data can easily become disorganized and lost into an individual staff member's files, creating additional work in the data collection and reporting phases, and perhaps even resulting in permanent loss of data when that individual moves on.

The other major reason that data management should be considered early in project planning is that data entry, quality control, analysis, and reporting require a substantial amount of time and labor, and thus should not be neglected in the project budget. The Level 2 springs inventory protocol produces a somewhat complex dataset with data from 12 major categories to enter, quality control, analyze, summarize, and properly archive. Without a well-designed data management system, this series of tasks will be difficult to implement efficiently.

A well-designed data management system will, at a minimum, be customized to the field survey protocol, and should be designed to facilitate data quality assurance and quality control, analysis, and reporting. It will also keep data organized and properly archived for future use.

Springs Online Database

SSI developed Springs Online—a secure, user-friendly, online database where users can easily enter, archive, and retrieve springs information (https://springsdata.org/; Fig. 8). This database is relational, providing the ability to contain multiple surveys for each site and to analyze diverse variables and trends over time. It is broadly framed to accommodate a wide array of variables and information needs. It supports data collected using several common protocols, including but not limited to the SSI Level 1 and Level 2 springs inventory protocols.

The several categories of data collected using the Level 2 inventory protocol are ecologically interrelated. For example, water quality is linked to springs flow rate, geology, geomorphology, soils, flora, and fauna. As a relational database, Springs Online provides a framework to address this ecological complexity and facilitates analyzing relationships among biological, physical, and cultural variables over space and time.

Because the Springs Online database structure and interface are customized for SSI and other agency spring inventory protocols, the data entry process is streamlined, with forms and data fields arranged to match the field sheets. The system is populated with drop-down fields that facilitate data entry, assure consistency, and minimize error. Buttons and tabs allow the operator to easily move between forms.

Springs Online includes the capacity to export summary reports of data, facilitating quality control, data analysis, and reporting (described in more detail below).

Perhaps the most unique and valuable aspect of Springs Online is the fact that it provides long term archival of data for multiple users with flexible built-in security. This powerful combination of traits promotes collaboration among springs stewards and facilitates trend analysis.

Springs Online's capacity is broad enough to include establishing baseline datasets, informing the assessment process, guiding monitoring, evaluating stewardship efforts, tracking restoration actions, and monitoring changes influenced by aquifer depletion, climate change, and other factors for individual springs, or for many springs across a landscape. The long-term value of such collaborative information management systems is the opportunity to share data with other springs ecosystem managers across political boundaries.

Stewards implementing a springs stewardship program should consider using Springs Online to manage their background and field data. This purpose-designed database is freely available online; users need only create an account and request appropriate permissions.

Reporting

Overview

Stewards who choose to enter their springs inventory data into Springs Online can automatically generate several different types of reports, as described below. An in-depth, frequently updated manual on how to manage information in Springs Online is available at the SSI website (**https://springstewardshipinstitute.org/database-manual-1**).

Individual Site Descriptions

Users of the Springs Online database can generate site-specific reports in Microsoft Word once the survey data have been entered. These survey summary reports include: the spring location with all georeferencing and geographic data, the names of the survey team members, the date and start and end time for the survey; a 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 include the species list, vegetation cover types and percent cover along with species nativity and wetland indicator status; fauna data including invertebrate and vertebrate taxa lists; assessment information from the SEAP defining the risk and condition of site-specific biology, geomorphology, aquifer functionality and water quality, habitat, and human influences; management recommendations; representative and additional photos of the springs ecosystem; flow measurements, water quality data, and sketchmap. A simple export into Microsoft Word format vastly simplifies report generation and allows project managers flexibility in editing.

Project Reporting

Springs Online users can also download a summary report describing all the springs in a project (Fig. 61). These reports are a compilation of individual site descriptions and are exported in Microsoft Word format. Users can also download project data in tabular (.csv) format, including a table showing all of springs in the project with the geographic coordinate, elevation, and springs type of each; other tables that report spring flow rates, water quality, and SEAP assessment scores; and crosstabs of plant, vertebrate and invertebrate species. These data exports can be conveniently used for data quality control efforts and additional analysis.

Trend Detection

Trend detection is a valuable and crucial part of monitoring. Data to inform trend analysis can be readily exported for any site or project in Springs Online, in the form of reports in Microsoft Word format and data exports in tabular (.csv) format. 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. See the Level 3 Protocol for a discussion on designing springs monitoring plans.

Landscape Analysis

Springs Online's capacity to export project-wide tabular data is a convenient first step toward synthesizing landscape-scale analyses of springs data. A landscape analysis should summarize all of the individual springs data from a project into a single document detailing all inventories undertaken. The result of this analysis might include the total number of springs inventoried, the number of reported springs locations where no spring was found, and the average and median area of springs surveyed. From the total number of springs reported on a landscape and the median area of surveyed springs, it is possible to estimate how much springs habitat exists within a landscape.

Further results of a landscape analysis might include summaries of water quality and flow data, with explanation of general trends of observed during surveys. A vegetation analysis might include reports of plant species richness and relative cover of native vs. nonnative species, and relative cover by functional group. These analyses can be completed for each spring individually and for the project as a whole. Similar analyses, examining species diversity and frequency, can be completed for vertebrate and invertebrate fauna.

SEAP results 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. SEAP analysis techniques are described in detail in Stevens et al. 2016. Managers can use this analysis to apply limited resources to those springs that have the greatest potential for improvement.

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Fig. 61. In Springs Online, the "Reports" tab allows for site or survey-specific reporting.

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