INVENTORY AND MONITORING PROTOCOLS

FOR SPRINGS ECOSYSTEMS

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INTRODUCTION

Springs Inventory and Stewardship

Springs are ecosystems of heightened management attention, serving as hydrogeologic windows into aquifers (Tóth and Katz 2006; Kresic and Stevanovic 2010), as critical water supplies, as keystone ecosystems (Perla and Stevens 2008), and as refugia for rare or unique species, remarkable paleontological repositories, and focal points of human cultural and development (Stevens and Meretsky 2008). However, springs have yet to receive substantial attention or protection from water or natural resource managers or policy makers: little significant attention has been paid to springs ecosystems in any major review of national water resources status in the past two decades (i.e., National Research Council. 1994; Mitsch and Gosselink 2000; Gleick et al. 2009; Baker et al. 2004; H. John Heinz III Center 2008; Wilshire et al. 2008; Boon and Pringle 2009; Solomon 2010; but see Minckley and Deacon 1991, Stevens and Meretsky 2008, and Kresic and Stevaovic 2010). This lack of recognition is partially due to the inherently complex and multidisciplinary nature of springs ecological research, the lack of a lexicon with which to describe different types of springs (Springer et al. 2008; Springer and Stevens 2009), jealous guarding of springs as domestic and agricultural water sources, and lack of legislative protection (Glennon 2002; Nelson 2008). Improving springs stewardship requires assessment, planning, implementation, and monitoring, all of which are best when based on rigorous, scientific inventory. Here we describe springs inventory and monitoring protocols that serve the purposes of ecosystem assessment and improved stewardship.

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

The inventory and monitoring protocols introduced here have been developed over the past decade and used on hundreds of springs of different types in different geomorphic and climatological settings. Our approach recognizes that many springs are under active anthropogenic management, use that is necessary for human well-being and often is fully intentional. While such use is fully recognized and respected, we suggest that springs can be managed sustainably to support ecosystem and landscape ecological functions as well as goods and services to the human steward(s). In general, if the aquifer is not degraded, springs ecosystems are remarkably resilient and can function well ecologically while simultaneously providing benefits to stewards. Sustainable management of springs should be a primary goal of stewardship, and while we have seen many successful examples of such stewardship, we have encountered far more springs that have been unnecessarily destroyed by poor management practices and neglect. Also, springs often can be rehabilitated or restored to an ecologically sustainable condition with relative ease or minor changes in management. Our perspective is that we should continue to work towards understanding springs ecosystem ecology and that, where used, springs should be sustainably managed for both societal and ecosystem functionality through inventory, assessment, conscientious planning, implementation, and monitoring.

Springs as Socio-ecosystems

Inventory and monitoring challenges often arise from an unfocused conceptual understanding of socio-ecosystem organization. Components of a comprehensive springs inventory follow from, and help refine the conceptual ecosystem model of Stevens et al. (2006), and include: aquifer mechanics and sustainability (Töth and Katz 2006; Kresic and Stevanovic 2010); flow and water quality (Meinzer 1923, Mundorff 1971, Springer et al. 2008; Trček and Zojer 2010; Kresic and Bonacci 2010); aquatic and wetland vegetation (Pattern et al. 2008); aquatic and wetland faunae (Erman 1992, Hershler 1994, Hershler et al. 1999, Williams and Danks 1991, Ferrington 1995, Botosaneanu 1998, Stevens and Bailowitz 2009); fish (Unmack and Minckley 2008); other vertebrates; cultural elements, including ecosystem goods and services (Nabhan 2008, Rea 2008, Phillips 2009); and the administrative context of springs stewardship, including regulatory issues (Stevens 2008). Relationships and feedback among the components and processes that shape springs ecosystems are often complex, with: multiple interacting physical processes; microhabitats each supporting different assemblages; and springs playing important roles in surrounding socio-ecosystems. For springs ecosystem ecology to advance as a science and contribute to stewardship, springs inventory data should be organized to test and refine understanding of these complex relationships (Stevens 2008).

Until recently, the scientific research and understanding of springs as socio-ecosystems has been insufficient to develop coherent, integrated inventory, monitoring, and data management protocols. Many short-term springs studies 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, but not on springs as ecosystems. Few springs have been subjected to long-term experimental and monitoring studies. Only three springs complexes in the United States have been studied in sufficient detail to understand ecosystem functions and changes over time. Silver Springs in Florida has received more than 50 years of scientific attention, beginning with the seminal ecosystem studies of Odum (1957) and continuing studies (Munch et al. 2006). Montezuma Well in central Arizona has been the subject of intensive studies by Blinn (2008) and his colleagues. Both of those springs are large limnocrene (pool-forming) systems with associated runout streams. Montezuma

Well is a fishless springs pool with the highest concentration of unique species of any point known to us in North America, as well as other rare species. Both springs complexes demonstrate remarkably high levels of primary and secondary production, have complex trophic organization, and are relatively small ecosystems at risk due to regional aquifer alteration. A third, well-studied group of springs ecosystems are those in Yellowstone National Park, where ecological gradient analyses reveal increased ecosystem variability and complexity as hotsprings water cools (e.g., Brock 1994). Additional springs ecosystem studies are underway, and we hope that improved understanding of springs ecosystem ecology will continue to emerge, and that our efforts here stimulate renewed interest in basic and applied springs ecosystem ecology.

Inventory Protocol Background and Development

The U.S. Environmental Protection Agency, Army Corps of Engineers, numerous federal and state land and water resource management agencies, indigenous tribes, various for-profit and non-profit non-governmental organizations, and many private individuals protect and manage ground and surface water quality, wetland and riparian ecosystem health and assessment, socio-cultural resources assessment, and other natural and social aquatic and wetland ecosystem functions (e.g., U.S. Fish and Wildlife Service 1979, 1980; National Research Council 1992, 1994; Brinson 1993; Davis and Simon 1995; Mageau et al. 1995; Society for Range Management 1995; Oakley et al. 2003; Sada and Pohlmann 2006; Stevens and Meretsky 2008; Kresic and Stevanovic 2010). In the United States, springs inventory and assessment protocols must be consistent with federal land and resource management legislation (e.g., the Antiquities Act of 1906, the National Park Service Organic Act of 1916; the multiple use mandates of the U.S. National Forest Service and the Bureau of Land Management, the Clean Water Act of 1973, the Endangered Species Act of 1973, etc.). Wetlands delineation in the United States (Army Corps of Engineers 1987) has consumed much technical and regulatory attention; however, delineation concepts and techniques are not universally applicable to springs, particularly naturally ephemeral springs, hot springs, hanging gardens, and other springs in bedrock-dominated landscapes. Misapplication of stream-riparian and wetlands inventory techniques, such as the Bureau of Land Management's proper functioning condition (PFC) can distort interpretation of springs ecological integrity (Stevens et al. 2005). Development of springs inventory protocols for specific regions, individual states, or individual agencies may not be broadly applicable, and therefore may not contribute to the advancement either of national or international springs conservation, or to improving springs ecosystem ecology (e.g., Stevens et al. 2006).

Some, but by no means all, existing technical aquatic, wetland, and riparian monitoring approaches are appropriate or useful for springs inventory and monitoring (Stevens et al. 2005, 2006; Sada and Polmann 2006). Inventory protocols for stream-riparian hydrogeomorphic techniques are useful for surfaceflow-dominated, and some rheocrene springs, but generally are inappropriate for springflow-dominated springs because of fundamental differences in geomorphic processes. Stream channel meander and bank configuration are shaped by flooding, whereas springflow dominated channels often tend to be linear or erratic. Also, beaver and large woody debris are widely regarded as essential to proper temperate stream-riparian functioning, but often play little or very different roles in springs ecosystems. Development of inventory protocols for Mojave Desert springs administered by the U.S. National Park Service (Sada and Pohlmann 2006), and coldwater New Zealand springs (REF) have been made; however, efficient, interdisciplinary inventory protocols are needed that are applicable to all types of springs -- subaerial or subaqueous, in any biome, and across political and national boundaries. Such protocols should help advance the springs ecosystem ecology and stewardship, which are actively developing fields.

Biological variables are often particularly important components of springs ecosystem management, and nearly all studies of springs to date have emphasized their biodiversity significance. Despite the miniscule total area occupied by springs in the United States, more than 16 percent of the nation’s endangered animal species are springs-specialist taxa. Also, high concentrations of rare species occur at some springs, in both aridland and mesic regions. Ecological risks to those springs from groundwater pumping and source alteration are numerous (Minckley and Deacon 1991; Stevens and Meretsky 2008). Regional, multi-springs inventories of biota include those for wetland plants (Patten et al. 2008, Spence 2008), Odonata (Stevens and Bailowitz 2009), aquatic Heteroptera (Stevens and Polhemus 2008), Coleoptera (Blinn 2008), Trichoptera (e.g., Erman and Erman 1990, Erman 1992, Blinn and Ruiter 2009), fish (Fagan et al. 2005), and other vertebrates. Such data provide a background for the scope of resources considered in inventory and monitoring.

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

Recent clarification of springs classification and ecosystem information needs (Stevens and Meretsky 2008) has set the stage for development of protocols to enhance systematic inventory and springs ecosystem research and stewardship. Here, we propose an integrated springs inventory protocol (SIP) to provide rapid, reliable, and readily understood information on springs ecosystem components, processes, threats, and stewardship options. The protocol recommended here can be used at any landscape scale of inquiry, from that of a single springs ecosystem, to inventorying springs on a regional, continental, or global basis, and can be used for monitoring to quantify ecosystem change over time. Elsewhere we present a database into which inventory data are easily compiled to archive and interpret inventory information. We have attempted to integrate selected existing methods into an efficient, integrated analysis at several levels of inventory intensity (which will vary based on available time and funding). The information compiled through the SIP will contribute to improved stewardship, as well as contributing to basic springs research, including groundwater basin definition, the distribution and importance of different types of springs within regions, and biodiversity patterns in relation to ecological gradients. Our SIP informs a comprehensive springs ecosystem assessment protocol (SEAP), allowing springs stewards to compare springs within landscapes, determine stewardship priorities, and monitor and measure the effectiveness of management actions over time.

BACKGROUND INFORMATION FOR SPRINGS INVENTORY

Need for Background Information

A synopsis of background information is needed by springs stewards, from those managing a single springs ecosystem for domestic water supplies, to those managing large landscapes with hundreds or thousands of springs. Relevant background information includes: 1) groundwater hydrogeology of regional aquifers, and including climate influences; 2) regional ecology and biodiversity, particularly of sensitive species; 3) sociocultural prehistory and history; and 4) land and resource management policy and legal issues. Such information provides critical basic information about individual springs or the springs within the region, and serves as baseline reference documentation. Much of such information may already be available, but it should be compiled into concise, well-referenced, archived reports, so that present and future stewards will have a clear understanding of the rationale and history of management decisions.

Regional Groundwater Hydrogeology: Knowledge of the status and responsiveness of regional aquifer hydrogeology is critical for understanding the condition and risks to the springs arising from those aquifers and in relation to climate variability and change. Typically, such information is compiled and integrated in a groundwater model. Such models take into account regional geologic stratigraphy and structure, permeability of parent rock and recharge capacity, climate variability, residence time, and well distribution and groundwater withdrawal history, and projected future withdrawal. A few examples of modeling analyses of springs discharge in relation to regional aquifer conditions include those for: Devils Hole, Nevada; 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 (Scott et al. 2004; Phelps 2004). Such studies play major roles in guiding aquifer management policy. Systematic compilation of springs distribution (as described in Level 1 inventory protocols, below) is included in this synthesis.

Regional Ecology and Biodiversity: Understanding the ecology and biodiversity of the region is important to recognizing the importance of individual springs as refugia for sensitive species, and their role as keystone ecosystems (*sensu* Perla and Stevens 2008). Springs ecosystems often interact with the surrounding uplands ecosystems by providing essential water, habitat, and food resources. In turn, springs are often strongly influenced by uplands biota and ecosystem condition. For example, removal of large predators (e.g., bear, wolf, and large cats) is likely to influence native and non-native mammalian herbivore populations, resulting in overgrazing and vegetation composition changes of springs (e.g., Yellowstone National Park wolf-elk interactions). Therefore, a description of the types and conditions of surrounding ecosystems is needed to develop understanding of such interactions.

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

Sociocultural Prehistory and Historical Use: Springs are among the most important cultural sites in the landscape, supporting paleoarcheological remains and containing evidence of prehistoric and historic use, and having enormous contemporary culture and economic value (e.g., Haynes 2008, Glennon 2002, Nabhan 2008, Rea 2008, Phillips et al. 2009). An integrated, annotated history of human occupation and management of the springs and surrounding landscape is needed to identify springs that have significant sociocultural significance. In North America, most large springs have been intensively used by humans for the past 12,000 yr, requiring stewardship planning to include human impacts in conservation planning (West and McGuire 2002; Kodrick-Brown and Brown 2007; Kodric-Brown et al. 2007).

Resource Management Policy and Legal Issues: Clarification of policy issues and ownership supersedes and is core to resource planning and stewardship. Governance policies and rights should be compiled in an annotated list to clearly define resource management authorities and guide planning, implementation, and monitoring activities. Groundwater and surface water rights and springs and adjacent land ownership should be clearly resolved and fully documented prior to any substantial management actions.

Administrative Considerations

Collection Permits: In addition to information compilation, springs work often requires research permitting from the agency or entity responsible for land management. Permits may be required for each land unit visited, including federal, state, local, and private permits, and permitting may delay the inventory. Also, appropriate repositories should be established for collected and preserved specimens. Voucher specimens should be obtained and stored in professionally curated collections for further research or potential litigation.

Springs Stewardship: Springs stewardship is best based on a scientific approach, including development of an effective administrative context, definition of goals and objectives, assembly of existing and needed information, assessment of information, prioritization needs and management action, and conduct of management and monitoring as scientific experiments, with forethought, data collection, review of results, and feedback into future management actions. If multiple stakeholders are involved in the management and decision-making on one or more springs, then scientific adaptive ecosystem assessment and management (AEAM) should be employed (REF). AEAM is the process of collaborative resource management to meet the needs of multiple stakeholders.

THREE LEVELS OF INVENTORY

Springs Inventory Levels

We developed the SIP though our experience inventorying more than 500 springs across the Intermountain West, particularly in the Great Basin (Sada and Pohlmann 2003) and on the Colorado Plateau (Springer et al. 2006), as well as in Florida, Pennsylvania, Wisconsin (USA), Alberta (Canada), and Sonora (Mexico). These protocols and databases embrace recommendations on springs inventory and monitoring made by Grand Canyon Wildlands Council (2002, 2004), Sada and Pohlmann (2006), Otis Bay (2006), Springer et al. (2006), Stevens et al. (2006), Stevens (2008), and under preparation by the U.S. National Forest Service.

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

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

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

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

As mentioned above, springs inventory data gathered from laboratory (mapping) and field site visits are compiled into a comprehensive, user-friendly springs inventory protocols (SIP) database and used to inform the springs ecosystem assessment protocol (SEAP).The SEAP provides springs stewards with clear interpretation of springs ecological conditions and risks from the manager's perspective.

The SIP database is broadly framed to accommodate a wide array of environmental settings and management needs. However, further testing and refinement of the SIP is necessary and desired, particularly in boreal and subaqueous environments. W recognize that springs 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 stewardship. Therefore, we have developed SIP and SEAP to remain as adaptive as possible, and we plan to continue to update these tools over time.

LEVEL 1 INVENTORY

A Level 1 inventory of the springs in a landscape is needed to define the distribution, access, springs types, and flow sampling equipment needs for Level 2 inventories. Given the generally low-resolution understanding of springs distribution in North America and elsewhere (Stevens and Meretsky 2008), 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 a landscape prior to conducting more intensive Level 2 inventories. In large landscapes, a Level 1 survey should be initiated by reviewing available map data, and by conducting interviews with knowledgeable individuals. Such efforts, conducted prior to Level 1 inventory field work, greatly reduce field search time and inventory costs.

Level 1 inventory field site visit protocols are described by Sada and Pohlmann (2006) and Stevens et al. (2006). A Level 1 springs site visit is a brief (10-20-minute) site visit for the purposes of georeferencing, photography, recording springs type, and determination of flow measurement equipment needs (Appendix A). Level 1 inventories are typically conducted by 1-2 trained individuals, such as technicians, scientists, or members of the educated lay public. This level of inventory is useful for identifying the distribution of springs in a landscape, and determining the need for a more rigorous Level 2 inventory. The information gathered in a Level

1 survey should include: georeferencing (with equipment or source, datum, and accuracy specified), directions on access to the site; the observer and date; a description of the springs and how to reach the site; photographs of the source and habitat array; the tyhpe of spring and approximate total area; the Level 2 protocol best suited to measure flow (e.g., capture, weir plate, flume, or wading rod); and notes on biota if possible. A Level 1 inventory can be performed during programmatic searches for springs or on an *ad libitum* basis as springs are encountered during other activities.

LEVEL 2 INVENTORY

Overview

Level 2 inventory includes an array of measured, observed, or otherwise documented variables related to site and survey description, biota, flow, and the sociocultural-economic conditions of the springs at the time of the survey (Appendix B). To the greatest extent possible, measurements and estimates are to be made of actual, rather than potential, conditions—a practice needed to establish baseline conditions and for monitoring comparisons (e.g., Stevens et al. 2005). The protocols presented here are compiled from the recommendations by Grand Canyon Wildlands Council (2002, 2004), Sada and Pohlmann (2006), Springer et al. (2006), Stevens et al. (2006), Springer et al. (2008), and Springer and Stevens (2009), and are based on the springs ecosystem conceptual model of Stevens and Springer (2006) and Stevens (2008). These variables constitute the suite needed to improve basic understanding of springs ecology, as well as the site's ecological integrity and developmental trends related to anthropogenic influences, including regional or local ground and surface water extraction or pollution, livestock or wildlife grazing use, recreational visitation, and climate change.

Level 2 inventory data are designed to be gathered during a 1.5-3 hr site visit by 3-5 trained specialists and assistants, with duration of the site visit primarily determined by the size and complexity of the springs. Level 2 staff should include a geographer, a hydrogeologist, a biologist with at least one assistant, and a socio-cultural expert. With proper planning and logistics coordination, Level 2 inventories costs should not exceed $2,500 per site in 2011 U.S. dollars, including data entry, with variation in cost depending on site remoteness and complexity, and the level of detail desired for water quality analyses. One-two additional days of office time per site are likely needed for compilation of background information, laboratory analyses, completion of data management, and reporting.

With appropriate background information, a single Level 2 site visit is sufficient for assessment of ecosystem integrity. The Level 2 inventory protocols and information management protocols recommended below are suitable for monitoring, and also can be used as a baseline for long-term Level 3 site management and restoration efforts. We consider a Level 2 springs inventory to be a rapid assessment of a site. We regard activities such as wetland delineation, soil profile analyses, paleontological and historical use investigations, and other in-depth scientific and management activities to be Level 3 activities, and therefore do not propose Level 2 inventory protocols for such efforts here.

In the following sections we describe the rationale behind selection of the variables considered important in a Level 2 springs inventory. The text guides the reader through the 5-page Level 2 field form (Appendix B). The inventory is designed with sufficient flexibility to add notes, observations, references, append data files, and information on unique or unusual features of individual springs, as they are encountered.

Level 2 Inventory Protocols

Site Description: A clear, concise description of the site and its microhabitats are essential for mapping the site, returning to the site for monitoring, establishing the elevation of the site in relation to the aquifer (useful for groundwater modeling), and relating other basic physical elements of the springs to its biota and uses. The first page of the Level 2 inventory field form (Table 1; Appendix B) includes a description of the spring's geomorphic context (site description) and its current condition, including notations of recent flooding, grazing impacts, fire, etc. (survey notes). It also includes the geographic location, access note, the physical characteristics of the site and its array of microhabitats, site photography (noting which camera was used), sketchmap preparation references, and the solar energy budget at the source. This first page is to be filled out by the geographer, in consultation with the other staff members. Most of the variables on the first page are self-explanatory using the one-page list of specific categories at the end of the field form and using Appendix B, but here we provide justification and commentary on the variables selected for measurement and information quality control.

Table 1: List and description of variables measured or observed during a Level 2 springs ecosystem inventory, and information sources: F – field site visit, L – laboratory analyses, O – office. See key in Level 2 field forms.

Variable Category	Variable	Description	Data Source
Site description	Spring name, country, state/province, county/municipality	General information about location of the site.	O
	Site code	A site code is created within the database to include the first 25 characters of the spring name, with spaces removed, the county or municipality, the state, and the country.	O
	Land unit and detail	Manager (NPS, USFS, private), and unit (eg. Grand Canyon National Park)	O
	Project name	Allows a set of surveys to be analyzed.	O
	Georeference: information source, datum, UTM zone, device, UTM easting, northing, latitude, longitude, elevation and accuracy (EPE, (m or ft), comments	Details of georeferencing	F
	General location and access	Site access directions.	F
	Date, start time, end time, surveyor's names	Who did the survey, when and for how long.	F
	Site sketch map	Hand drawn map, aerial photograph, or digitized map with scale, orientation, date, observers, landmarks, georeferencing points, photo points. Indicate location of the sketchmap (attached, computer, etc).	F

Variable Category	Variable	Description	Data Source
	Polygon code description	Identify each discrete geomorphic microhabitat	F
	Polygon area; surface type and subtype; slope variability (none, low, medium, high); cardinal aspect (MN or TN); soil moisture, water depth; % composition by surface substrate particle size including organic soils; soil type (wetland delineation, if applicable) and geochemistry; % cover of precipitate, litter, wood; average litter depth; wetted area	Describe the size, unevenness, aspect, and surface covers of the polygons.	F/L
	Site description and survey notes	Describe the landscape setting and springs type, and site conditions, including extent and forms of human alteration of the site, at the time of the survey.	F
	Photography	Describe details of photographs taken, indicate photo sites on the sketchmap, and include which camera was used.	F
	Solar radiation budget	Sunrise and sunset using a solar pathfinder to calculate otal % seasonal and annual solar flux (SF); sum mean winter, spring, summer, autumn and total annual direct SF and percent	F
Biotic inventory	Aquatic, wetland, and terrestrial plant species inventory	List of species detected, noting endemic and non-native taxa; visual estimation of % cover in each polygon by stratum: ground cover (0-2 m graminoid/herb/non-woody deciduous), shrub cover (0-4 m woody perennial), mid-canopy cover (4-10 m woody perennial), tall canopy cover (>10 m woody perennial).	F/L
	Aquatic, wetland, and terrestrial invertebrate species inventory	List of species detected, noting endemic and non-native taxa; quantitative data collection type, species enumeration, substrate, depth, velocity notes by microhabitat.	F/L
	Aquatic, wetland, and terrestrial vertebrate species inventory	List of species detected, noting endemic and non-native taxa, extent of grazing or browsing damage.	F/L
Geomorphology	Emergence environment	Cave, subaqueous, subaerial, other.	F
	Flow forcing mechanism	Gravity, thermal pressure, etc.	F

Variable Category	Variable	Description	Data Source
	Hydrostratigraphic unit: geologic layer of aquifer, rock type	Describe parent rock and rock type.	O,F
	Channel dynamics	Surface vs. springflow dominance.	F
	Source geology and flow subtype	Springs emergence: contact, fracture, seepage, tubular.	F
	Sphere of discharge and secondary sphere by polygon	Describe the springs type and subtype: Cave, limnocrene, rheocrene, mound-form, helocrene, hillslope spring, gushette, hanging garden, geyser, fountain, hypocrene, paleocrene.	F
Flow	Flow consistency	Describe perenniality of flow from long-term records or history, geologic features, dendrochronology, presence of aquatic organisms.	F/O
	Flow measurement technique(s), location, mean rate	Replicated flow measurement using techniques described; note measurement location.	F
Water Quality	Field WQ parameters: Time of day; air and water temperature at source; pH; specific conductance @25µm/cm; concentrations of dissolved oxygen, alkalinity (CaCO3, HCO3)	See Appendix B for protocols.	F
	Laboratory WQ: Concentrations of base cations and anions, total dissolved solids, H and O stable isotopes (d18OVSMOW and dDVSMOW)	See Appendix B for protocols.	L
Cultural resources	Archeological resources	Archeological surveys, literature review.	O,F
	Contemporary cultural resources (TCP, ethnobiology, etc.)	Interviews with tribal elders, botanical inventory, site visits with tribes, literature review	O,F
	Historical resources, histories	Historical surveys, literature review, interviews with elders	O,F
Bibliography	List of citations	List of citations	O
QA/QC	Data collection and data entry QA/QC	Analytical and information QA/QC, and management methods and efforts documentation	O

Springs Names, Georeferencing, and Polygon Definition: The database relies on the springs name and date for locating the inventory. In cases where springs have been named on geologic maps, that name should be used. In cases where no springs name exists, we suggest that the inventory team gives the springs complex a distinctive, colloquial name, a creative name that honors the site. In our experience, very few springs have only a single source and therefore, we prefer to name the site in plural form, such as “Vulcans Well Springs”. We recommend against naming a springs complex as “Big”, “Warm”, “Cold”, “Rock” Springs or by the dominant vegetation type (e.g., “Cottonwood”, “Sycamore”, or “Willow” Springs), as such names are greatly overused and, in the latter case because vegetation may change through time. It is customary in the United States to forego the use of apostrophes in geographic names. Because the U.S. Geological Survey governs the naming of geologic features in the United States, we recommend adding the word “Unnamed” to the latter part of the name so that it can be distinguished from officially named springs (e.g., “Broken Ax Springs Unnamed”.

Georeferencing guidance is provided in Appendices A and B. Accurate elevation data are essential for groundwater modeling; however, accurate data are notoriously difficult to obtain in cliff-dominated landscapes. Therefore, using topo maps or a digital elevation model may be more accurate than using GPS data.

Geomorphic microhabitats (polygons) should be described to determine the area, geomorphic diversity, plant species density, and other characteristics of the site. These microhabitats are patches that form through different physical and geomorphic processes, and description of microhabitats is best accomplished through an on-site discussion among all staff members. The common springs types and geomorphic microhabitats are listed in Springs and Stevens (2009). It is important to differentiate geomorphic microhabitats from vegetation, as one vegetation type may occupy portions or several entire microhabitats.

Sketchmap**:** Once the microhabitats have been identified, the geographer should field map them on an ortho-rectified site photograph, field tablet, on graph paper, measuring the dimensions and cardinal orientation of the polygons (e.g., Fig. 1). The length and width of the site should be measured with a metric tape or rangefinder. Once the site is outlined, the sketch map should include distinct features, such as: 1) site name, surveyors, date, a measurement bar; 2) a sketch of the site to approximate scale, with flow direction, springs orifice(s), the configuration of associated channels, pools, terraces, and other landforms indicated; 4) points at which georeferencing, photograpy, and Solar Pathfinder (see below).measurements were taken; and 4) roads, trails, spring boxes, pipes, troughs, and other constructed features. The sketchmap is scanned into the database, and included along with site photos in the archives.

An array of variables are measured or observed in each microhabitat and recorded on the data sheet, including: polygon area; surface type and subtype; slope variability; cardinal aspect; dip angle (slope angle); soil moisture level; water depth (if any); and percent of the polygon covered by different surficial substrate grainsizes, salt precipitate, litter, wood; average litter depth; and the wetted area. Surficial substrate grainsize follows the scale: 1 = clay, 2 = silt, 3 = sand, 4 = pea gravel, 5 = coarse gravel, 6 = cobble and small boulders (0.1 – 1.0 m in diameter), large boulders (>1 m diameter), 8 = bedrock, and 9 = organic soil. Soil types should be noted, if possible. We regard Clean Water Act wetland delineation as a Level 3 activity; however, it may be conducted if a separate, qualified wetlands delineator is added to the inventory staff.

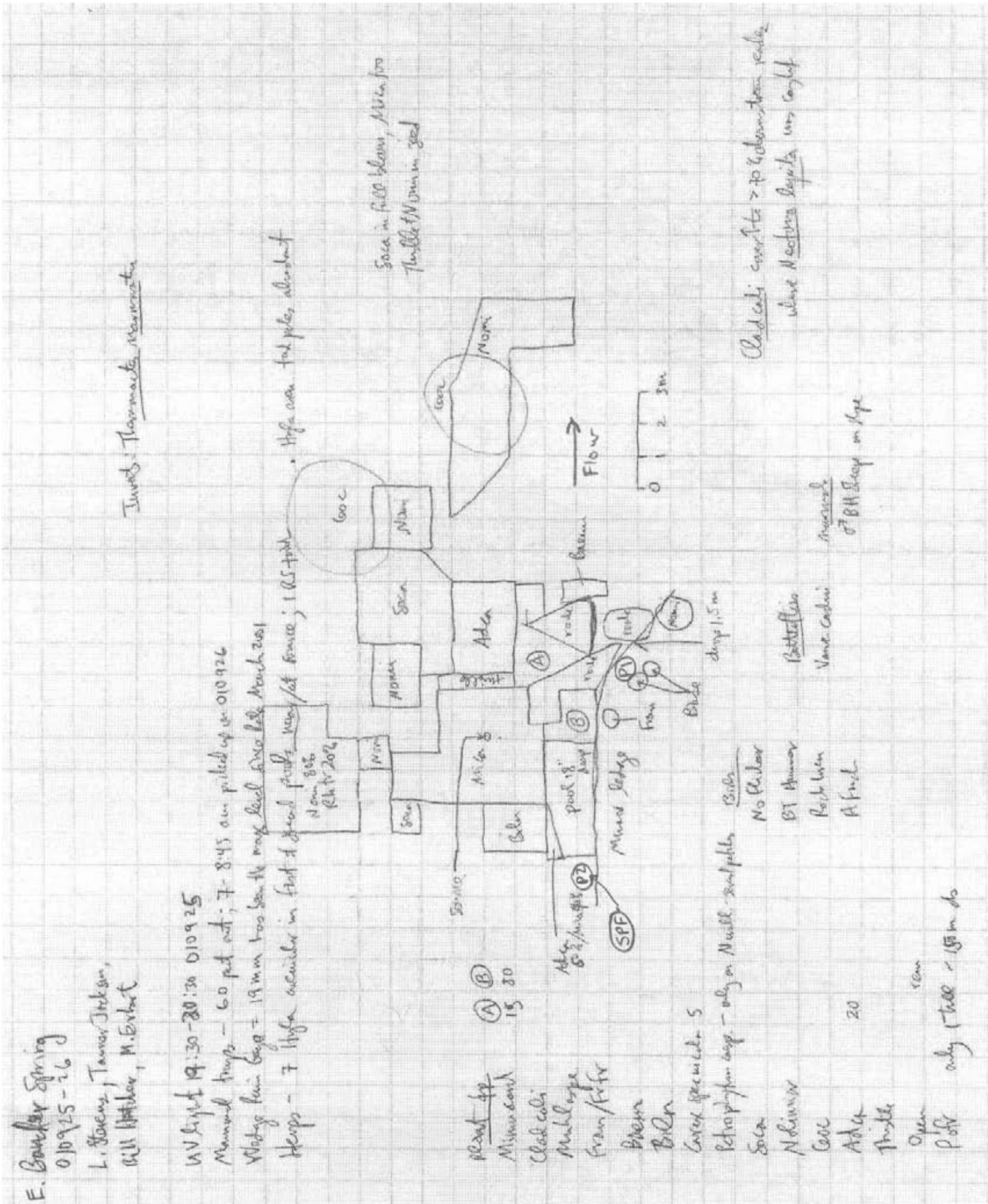

Fig 1: Example of a site sketch map from East Boucher Spring, Grand Canyon National Park, AZ, 15-16 September 2001 (GCWC 2004).

Solar Radiation Budget: The solar energy budget is important to springs because it determines the amount of light available for photosynthesis by springs vegetation, the duration of freezing in winter, and evaporation and relative humidity in the summer months. A Solar Pathfinder (SPF; Solar Pathfinder Inc. 2011; http://www.solarpathfinder.com/) can be used to determine mean monthly duration of direct insolation using the standard protocols defined by Solar Pathfinder, Inc. The SPF consists of a reflective, transparent dome mounted on a template of the sunpath diagram specific to the latitude of the site. The template contains the percent of solar insolation for half hour intervals between sunrise and sunset for each month. The percent total available solar energy for an average day during any month can be calculated. With a 1-2 minute measurement, the geographer can determine the site's direct solar radiation budget for the entire year. We recommend that three SPF measurements should be made at the source for comparative purposes, and the average reported. The instrument should be calibrated against actual sunrise and sunset times when such opportunities exist at an array of sites. In general, we have found the SPF to be accurate to within approximately 0.5 hours, and within 5 meters.

The Solar Pathfinder is by far the most efficient and least expensive approach to microsite collection of solar radiation data. Even the finest resolution topographic maps cannot provide information on local topography needed to model microsite insolation, and the SPF can be used to map solar energy budget around the perimeter of larger sites. Alternatively or for Level 3 research, a pyranometer and weather station data may be installed for monitoring temperature, precipitation, humidity in relation to solar radiation.

Flora

All plant taxa detected on the site are identified to the species level, and nativity and visually estimated percent cover (VE%C) are recorded for each species polygon by stratum within each polygon (Bonham 1989). Vegetation transect methods are inefficient for Level 2 rapid assessment, but may be used in Level 3 efforts. Vertical structure in each polygon is documented in five strata: aquatic (including algae and emergent taxa), ground cover (annual herbaceous and graminoid), shrub cover (0-4 m perennial woody), middle canopy (4-10 m tall woody), and tall canopy (>10 m tall woody). VE%C is inherently subject to inter-observer bias, with only coarse levels change detection anticipated. We generally find that VE%C is more accurately accomplished through discussion among the biologist and the bio-assistant, and is more consistent when crew training and membership is consistent. Plant species that cannot be determined on-site by the staff biologist should be collected, labeled as to site, date, and polygon, and returned to the laboratory for identification. Note that a given plant species may occupy several strata: for example, cottonwood trees may be present as seedlings (ground cover), and mature trees may occupy shrub, mid- and tall-canopy space.

Several features of the database aid in data entry, error checking, and reporting. Plant species taxonomy and nativity within biomes are archived in the database in a look-up table that automatically prevents taxonomic typographic errors during data entry. VE%C by polygon, stratum, and nativity are summarized in an automated report within the SIP database, saving a great deal of analytical and reporting time. The SIP database distinguishes "stratum taxa" from total species richness in the automated vegetation reports.

Fauna

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

Aquatic Fauna: Aquatic and wetland life at springs commonly includes: Mollusca, Hexapoda, and other invertebrates; fish; amphibians and occasional reptile taxa; and avian and mammalian taxa. Taxa that are prone to endemism at aridland springs in the USA include: hydrobiid springsnails (Sada and Hershler 2002, Sada and Pohlmann 2003); physid aquatic snails; aquatic amphipods and isopods (Blinn 2008); various families of stoneflies; several families of Heteropteran (especially Nepomorpha) waterbugs (Stevens and Polhemus 2008); dytiscid, elmid, dryopid, and psephenid beetles; cyprinodontid pupfish; cyprinid and cyprinodontid minnows (Nelson 2006); other fish; and amphibians (e.g., http://www.pwrc.usgs.gov/naamp/index.cfm?fuseaction=app.protocol). These references generally include habitat and sampling information. In addition, rare but non-endemic taxa, as well as potentially new taxa to science may be detected during springs surveys (Sada and Hershler 2002, Sada and Polhmann 2003, Stevens and Meretsky 2008, Stevens and Polhemus 2008, Stevens and Bailowitz 2009). Techniques for sampling vary by taxon, and require specific equipment, preservation protocols, as documented in Appendix B, and therefore require considerable field and laboratory expertise.

Many aquatic animal taxa can be documented with the first Level 2 site visit, however, Grand Canyon Wildlands Council (2004) reported that several seasonal site visits in different seasons and years were needed to detect 90 percent of the aquatic macroinvertebrate taxa present. For aquatic invertebrates, we recommend intensive spot sampling to detect as many of the species present as possible (Appendix B). Care should be taken to document species in various microhabitats, including riparian and aquatic vegetation, shoreline, madicolous, pool surface, water column, benthos, and hyporheic zones. If sufficient flow exists, quantitative benthic sampling also is appropriate to establish baseline abundance density (number of individuals per m^2) and species density (number of species per sample or per m^2). Quantitative benthic sampling techniques involve timed, replicated, and area-specific kicknet, Surber, Hess basket (mesh sizes of $\leq$1 mm), or petite Ponar dredge sampling, as described by Merrit and Cummins (2008) and in the Environmental Protection Agency monitoring compendium (http://www.epa.gov/owow/monitoring). If possible, at least three quantitative samples should be collected; ideally sampling should be conducted until variance in abundance stabilizes. Drift sampling also may be informative, but we generally regard it as being employed in Level 3 efforts. Sampling for fish involves D-netting, seining, or backpack electroshocking, depending on project information needs, with catch per unit effort as a standard monitoring metric. Great care must be exercised if protected species are present, and specific instructions about such species should be detailed in the project permit.

All nets, other sampling equipment, boots, and other materials that touch springs waters should be sanitized after each site visit to prevent the spread of chitrid fungi and other pathogens among springs and other water bodies. Birmingham-Southern College (http://www.alaparc.org/Initiatives/BSC_Sanatizing-Field-Gear.Apr14.2010.pdf) recommends spray-application of at least a 1% bleach solution to nets and other aquatic field equipment, with thorough rinsing following sterilization, and containment of runoff from the bleach spray and rinse, as these solutions are environmental contaminants. Placing the field equipment on a small plastic sheet can facilitate the equipment sterilization processs.

Aquatic and soft-bodied specimens usually are preserved in 70-80% ethanol and returned to the laboratory for sorting, enumeration, and identification. In situations where genetic analyses are planned, specimens should be preserved in 90-100% ethanol in a cool, dark environment. As such laboratory tasks are time consuming and expensive, we recommend development of a voucher collection within the land management unit to expedite future studies, monitoring, and Level 3 efforts. Specimens should be curated and preserved in accord with long-term museum conservation standards.

Terrestrial Fauna: Wildlife use of springs can be surprisingly intensive. For example, Grand Canyon Wildlands Council, Inc. (2002) reported 35 bird species, some in great abundance, watering at a small, remote spring on the North Rim of Grand Canyon during a single 2-hr Level 2 site visit, and commonly found 2- to 5-fold higher butterfly and avian density and species richness at springs as compared to the surrounding uplands. Although many terrestrial vertebrate species may be detected during a single site visit, developing a relatively complete list of the species present will requite numerous visits at different times of the year, which should be one of the goals of Level 3 efforts. Documenting the use of the springs by terrestrial fauna is important for understanding the ecological role of the springs to the surrounding ecosystem. A wide array of terrestrial macroinvertebrate taxa may be present, including: aerial adults of taxa with aquatic larvae (e.g., Odonata and many Diptera), and terrestrial arthropods, amphibians, reptiles, birds, and mammals. Because of the possibility of encountering endemic springs invertebrates, collecting should focus on non-quantitative invertebrate spot sampling and the use of sweep and beating nets. While all wildlife observations and techniques should be noted, quantification of terrestrial invertebrates, and quantified inventory of terrestrial vertebrates is recommended as Level 3 tasks.

Flow and Geochemistry

General Considerations: Springs flow is one of the most useful and important variables to measure, but is sometimes is difficult to measure accurately. It and geochemistry add great insight into understanding aquifer mechanics and subterranean flow path duration. Modeling of flow variability usually requires multi-decadal monitoring data, so collecting flow data during each site visit is very important.

Flow: The field sheet provides space for documenting the method(s) used to measure springs flow, ranging from standard streamflow cross-section velocity measurement, to the use of portable flumes or weirs, to simple timed capture of flow in small springs, or measurement of wetted patch area (Appendix B). For subaqueous rheocrene springs that emerge over some distance along the floor of a stream, difference methods can be used to estimate flow. However, measurement in subaqueous lentic settings, such as lake floors or marine settings, involves measurement of the area and velocity of discharging flow. Level I inventory data can help inform the hydrogeologist as to what types of equipment are needed for flow measurement. Replicated flow measurements are needed to develop a trustworthy mean value and ascertain uncertainty around the measurement, and we recommend that at least three measurements be made and the average calculated.

Water Quality: Field and laboratory water geochemistry methods have been defined by the U.S. Geological Survey and the Environmental Protection Agency. In general: 1) air and water temperature, pH, specific conductance, and dissolved oxygen concentration should be taken using calibrated field instrumentation at the source (rather than a convenient spot downstream from the source); and at least one filtered 0.1 L water quality sample should be collected in triple acid-rinsed bottles for laboratory analyses of major cations and anions and nutrients; and 3) 1-2 filtered water samples should be collected for stable isotope analyses in triple acid-rinsed 10 ml bottles. Samples are generally stored on ice but not frozen, and following standard sample storage and time-to-analysis protocols.

Sociocultural and Historical Inventory

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

LEVEL 3 INVENTORY

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

SITE CRITERIA

Site Selection

To be informative and useful to stewards, springs inventories in large landscapes (e.g., national parks, forest, tribal reservations) should both address stakeholder information needs and should meet appropriate stastistical sampling criteria. However, these criteria are not easily combined, except in situations in which most or all springs in a landscape are inventoried. Most stewards have questions about specific, high priority springs, and such springs are likely to be the largest and those with the highest potable water quality in the land unit. Dozens or hundreds of other springs may exist in the land unit, about which the steward may only want general information (but groundwater modeling may benefit from the flow and geochemistry of all springs in the landscape).

It appears to us that the best sampling strategy involves the following steps. 1) Conduct Level I inventory of the entire landscape. 2) Conduct Level 2 inventory and assessment at the steward's high priority sites. 3) Conduct Level 2 inventories and ecosystem health assessments at an array of several dozen randomly selected springs, stratified by springs type and across the land unit. If georeferencing and elevation data exist, a cluster analysis can be used to statistically distinguish within and among clusters of springs. 4) Use the results of (1) and (3) above to determine whether (3) provides sufficient insight into the general condition and risk of springs in the land unit. Further Level 2-III work should be divided between monitoring of previously visited high priority sites and randomly selected sites. Over time, such a strategy will maximize trend assessment and will eventually complete the Level 2 inventory.

Timing Site Visits

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

INVENTORY INFORMATION MANAGEMENT

Level I and Level 2 inventory protocols are developed on the assumption that the steward(s) will undertake and maintain a long-term information management program. In the case of large landscape management units (national parks, forests, Tribal reservations, etc.), such information management systems should be related to the steward's geodatabase and geographic information system, and such stewards are likely to have data archival, site photography, specimen curation, and clearly defined metadata and reporting standards. The springs information management system and its metadata should be easily accessed, should be entirely secure to protect sensitive data, and should readily allow for additional or new analyses. Few such data management systems presently exist for springs ecosystems, but the long-term value of such information management systems is the protection and sharing of data with other springs ecosystem managers. We present a comprehensive database and information management system in the SIP database, along with commonly requested auto-formatted reports.

The need for data quality control places primary responsibility for data accuracy and entry on the field technician(s) who collected the data, and who should promptly enter field data into the SIP database. All field data should be preserved in electronically scanned or hard copy formats. All data entry should be overseen and checked by the project supervisor or by the information manager. Data entry errors and data checking should be documented and corrected.

Our SIP database is designed to flag outstanding values for many variables and to maximize veracity of the data, but information quality assurance is ultimately the responsibility of the data entry and quality control team. Our SIP database automatically tracks changes to data with a date stamp and a login name. A QA/QC form on the first page allows the project technicians and supervisor(s) to enter their names and the data checking dates, as well as comment fields.

At present, we do not endorse the practice of on-site electronic data entry, as field sheets are more efficient for Level 2 multi-staff team information compilation, and detection of data entry errors is impossible with electronic field recorders. Therefore, we recommend that data entry from field sheets should be conducted by the the field technician(s) in the laboratory promptly after the data are collected, and checked by the project or information manager.

CONCLUSIONS

With the above inventory recommendations, we hope to advance springs information collection for improved understanding of springs condition, ecosystem health, monitoring, and stewardship. The collection and, where appropriate, sharing of information about springs in and across regions will greatly advance springs ecosystem ecology by revealing patterns about which we presently have little insight. Numerous hydrogeological questions require large integrated datasets, including: 1) characterization of springs geomorphology by type, 2) springs stream channel form and function; 3) relationships between geochemistry and landform-microhabitat structure; and 4) strategies and variation in best restoration practices for different types of springs. Addressing ecological questions about springs similarly require large, integrated data sets, and such questions include: 1) Are geomorphic and biological diversity related at springs; 2) How do latitude, longitude, aspect, and elevation interactively affect plant assemblage structure and complexity? 3) Does plant architecture and composition vary predictably among different springs types? 4) Do springs flora and fauna follow standard insular biogeography patterns based on habitat patch size and distance from other springs? 5) How and to what extent is endemism at springs a function of water quality? 6) Is the sociocultural diversity of springs related to their geomorphic and biological diversity? These and other macroecological questions can be answered only through compilation of large-scale systematic and statistically credible inventory efforts (Stevens 2008).

Integrated springs stewardship planning and implementation is one of the most conspicuous gaps in conservation ecology today, and its one that requires dedicated information collection and management. We propose the above approaches for springs inventory in the hope that such methods will lead to improved understanding and more coherent, intentional management of these remarkably diverse, rich, and highly threatened ecosystems at local, regional, national, and international scales.

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APPENDIX A: LEVEL I SPRINGS INVENTORY PROTOCOLS

INTRODUCTION

Overview

A Level I Springs Ecosystem Inventory should be completed in 15-30 minutes by 1-2 staff trained in Level 2 site georeferencing, characterization, and flow techniques assessment. The Level I inventory involves: 1) description of access and springs type; 2) acquisition of coordinates (usually as global positioning satellite data); 3) taking site photographs; 4) determining which flow measurement technique(s) are needed; and 5) recording notes about the structure and general biota of the springs. Fill out as much of the Level I inventory sheet (Appendix A.1 as can be done efficiently based on your level of training.

Access

Document the map used and describe in detail the best route to access the springs and any landmarks that may help guide the Level 2 team.

Georeferencing

Record the site name, land management unit, identification number (if any), township or range, section, topographic quad map name and scale. If using a GPS unit, record the make and model, the datum, elevation, and error.

Springs Type

Describe the springs type, based on the classification systems of Springer and Stevens (2009). Springs types include: *rheocrene* (arising in a well-developed channel), *shallow or steep hillslope* (arising on a shallow or steep hillside), *hanging gardens* (contact springs on a cliff face), *limnocrene* (pool-forming springs), *helocrene* (fen, wet cienega, or marsh-forming springs), *mound-forms* (travertine mounds), *gushets* (pouring, concentrated flow from a cliff face), *geyser* (eruptive hot springs), *fountain* (cool-water artesian), *hypocrene* (springs at which groundwater approaches, but does not reach, the surface; and *paleosprings* (former springs no longer flowing).

Flow Measurement Technique

Describe which of the flow measurement techniques described in Level 2 (Below) is needed to measure flow at the springs.

General Comments

Describe the structure and general vegetation cover of the springs (e.g., an open marsh, under heavy coniferous forest, etc.). Record any species of plants and animals you recognize at the site.

Site Photography

Take diagnostic photographs of the site from easily rematched locations. Photo points should be selected in relation to fixed objects, such as large rocks. Photographs should document the springs sources, landforms, other landmarks, and uplands. Photo metadata can be recorded on the datasheet, including camera type, film speed, focal length, aperture or F-stop, and a photo description. Photographs of the photopoints are useful for rematching photographs.

EQUIPMENT LIST FOR LEVEL I INVENTORY

- Datasheet and pencils
- Topography map of site (USGS quadrant)
- Handheld thermometer
- Camera and film
- GPS unit
- Compass

LEVEL I SPRINGS INVENTORY FIELD DATA SHEET

Site: Record the site name as it appears on topography maps or official documents; ID No.: Site identification number; Land *Managing Unit:* The agency, organization, or private landowner that manages the land (i.e. National Park, Forest Service); *Township/Range:* on 7.5' topo map; **Section:** on 7.5' topo map; **Date:** yymmdd; **Time:** military: ex. 1330 is 1:30, and or UTMs or latitude-longitude in NAD83 or WGS84 datum.

Contact Person/Information: Fill in the full name of the contact person, affiliation, and contact information.

Access Description: Provide the name of the topographic map quadrant, and detail on access, using prominent features. For example, approximately 50m SW of the Tanner Trail on the south rim of the Grand Canyon.

Site Description: Describe the geology of the site, recognizable plants and animals, evidence of historical channels, water saturation, and evidence of human impacts on the site, including: dams, diversions, structures, activities, etc.

Flow Description: Describe flow out of spring source in detail. Example: spring slowly flows out of orifice, trickles (20cm wide 2cm deep flow) for 20 m and disappears; flow approximately 1 L/s. **Evaluate which type of flow measurement device will be required (collection tubes and containers, weir plate, flume, etc.).**

Spring Type: Select the spring type based on the descriptions described below.

Type	Description
Cave springs	Emerge entirely within a cave environment and not directly connected to surface flow
Limnocrene springs	Emerge as one or more lentic pools
Rheochrene springs	Emerge as flowing streams
Mound-form springs	Emerge from (usually carbonate) precipitate mounds
Heleocrene springs	Emerge usually in a diffuse fashion in cienega (marshy, wet meadow) settings.
Hillslope springs multiple	Emerge from non-vertical hillslopes at 30-60^o slope, and usually have indistinct or sources
Gushet springs	Pour from cliff faces
Hanging gardens	Complex, multi-habitat springs emerge along geologic contacts and seep, drip, or pour onto underlying walls
Geysers	Geothermal springs that emerge explosively and usually erratically
Fountain springs	Cool-water artesian springs that are forced above the land surface by stratigraphic head-driven pressure.
Exposure springs	Settings in which ground water is exposed at the surface but does not flow
Hypocrene springs	Springs in which ground water the water never reaches the surface

Habitat Type:

Type	Description
Cliff face	Vertical rock wall, with minor vegetation growth
Marsh	Wet meadow
Riparian	Riparian vegetation(e.g., cottonwood, willow, tamarisk)
Pools	Standing water
Stream Bank	Side of an ephemeral channel-highly disturbed
Other: _____________	Describe other type

Photo points should be selected in relation to distinct fixed objects, such as ledges or large rocks. The reference points should be located within 60m of the photo point and include the riparian zone, distinguishing landmarks, upland vegetation and the spring source. Two site photo(s) should be taken approximately 45^o apart from the same location for potential future use in mapping, where possible. A GPS reading should be taken of the landmarks in the photos and the latitude, longitude, and the accuracy should be recorded on the datasheet. The photo number on the roll and number of roll of film should be recorded on the datasheet. Record camera type and the direction of the photo using a compass (e.g., West at 250 degrees magnetic north), and a brief photo description.

APPENDIX B:
PROTOCOLS, CRITERIA, AND FIELD DATA SHEETS FOR LEVEL 2 SPRINGS ECOSYSTEM INVENTORY AND MONITORING

INTRODUCTION

This appendix provides instructions for conducting Level 2 springs inventories, and the methods also can be used for monitoring springs ecosystems over time. A Level 2 inventory includes measurement, observation, estimation, or other documentation of variables related to site and survey description, biota, flow, and the sociocultural conditions of the springs at the time of the survey. To the greatest extent possible, these variables are of actual, rather than potential, conditions, a necessary practice for use in establishing a baseline and in monitoring (e.g., Stevens et al. 2005). The variables are compiled from the recommendations by Grand Canyon Wildlands Council (2002, 2004), Sada and Pohlmann (2006), Stevens and Springer (2005), Springer et al. (2006), the Springer et al. (2008) and Springer and Stevens (2009) classification system, and the springs ecosystem conceptual model (Stevens and Springer 2004). These variables constitute the suite needed to improve basic understanding of springs ecology, as well as the site's ecological integrity and developmental trends in relation to anthropogenic influences, including regional or local ground and surface water extraction or pollution, livestock or wildlife grazing use, recreational visitation, and climate change.

Level 2 inventory data are designed to be gathered during a 1.5-4 hr site visit by 3-5 trained specialists and assistants, with duration of the site visit primarily determined by the size and complexity of the springs. Level 2 staff should include a geographer, a hydrogeologist, a biologist with at least one assistant, and a socio-cultural expert. With proper planning and logistics coordination, Level 2 inventories cost ≤ $2,500 per site visit in 2010 U.S. dollars, depending on site remoteness and the level of detail desired for water quality analyses. In addition to field time, 1-2 additional days of office time per site are likely to be needed for compilation of background information, laboratory analyses, completion of data management, and reporting. With appropriate background information, a single Level 2 site visit is sufficient for assessment of ecosystem integrity through use of the springs ecosystem assessment protocol (SEAP), and can be used as a baseline for long-term monitoring, Level 3 research, and monitoring restoration efforts.

In the following sections, we describe the rationale behind selection of the variables considered as important in a Level 2 springs inventory. The text guides the reader through the 5-page Level 2 field form, with a definitions page for scoring, and a single sheet of graph paper for sketchmapping. This Level 2 inventory is designed with sufficient flexibility to add notes, observations, references, append data files, and information on unique or unusual features of individual springs, as they are encountered.

The data sheets and scoring criteria are attached in *.pdf format in this appendix for ease of printing. One set of data sheets is to be filled out for each site visit. The data sheets are designed for ease of data entry, and the sheets and sketchmap should be electronically scanned, or preserved in hard copy form, and permanently archived. All categories of variables require quality assurance and quality control of the information gathered. Field information is best entered by the field technician(s), and all data should be checked by the project supervisor o the information manager.

LEVEL 2 INVENTORY PROTOCOLS

Site Description

Site Geography: The first page of the Level 2 inventory field form (Table B1) includes description of the survey, the geographic location and access, physical characteristics of the site and its array of microhabitats, site photography, sketchmap preparation, and solar energy budget. This first page is to be filled out by the geographer, in consultation with the other staff members. Clear, concise description of the site and its microhabitats are essential for being able to map the site, for returning to the site for monitoring, establishing the elevation of the site in relation to the aquifer (useful for groundwater modeling), and relating other basic physical elements of the springs to its biota and uses. The variables are explanatory using the one-page list of specific categories at the end of the field form.

The SIP database used the springs name and date for locating the inventory, which also receives a unique number. In cases where springs have been named on geologic maps, that named should be used. In cases where no springs name exists, we suggest using a distinctive name, and we recommend against naming a springs as “Big”, “Warm”, “Cold”, “Rock” or by the dominant vegetation type (e.g., “Cottonwood”, “Sycamore”, or “Willow” Springs), as such names are overused and, in the latter case because vegetation may change through time. In our experience very few springs have only a single source and therefore, we prefer to name the site in plural form, such as “Vulcans Well Springs”. It is customary in the United States to forego the use of apostrophes in geographic names. Also, if springs are colloquially named during a survey, placing the name in quotes on the field sheet will distinguish the colloquial from a formal name.

Georeferencing involves collection of accurate easting and northing or latitude-longitude data, as well as elevation data needed groundwater modeling; however, accurate data are notoriously difficult to obtain in cliff-dominated landscapes. Thus, northing and easting data estimating springs elevation on a 7.5’ topographic sheet or in a digital elevation model may be more accurate than using a GPS.

Geomorphic microhabitats (polygons) are described and mapped to document their area, geomorphic diversity, plant species density, and other characteristics of the site. These microhabitats are patches that form through different physical and geomorphic processes, and description of microhabitats is best accomplished through an on-site discussion among all staff members. The common springs types and geomorphic microhabitats are listed in Table B1. It is important to distinguish geomorphic microhabitats from vegetation, as one vegetation type may occupy portions or several entire microhabitats.

These and subsequent measurements require an array of equipment. Table B2 provides a list of Level 2 field equipment.

Table B1: List and description of variables measured or observed during a Level 2 springs ecosystem inventory, and information sources: F – field site visit, L – laboratory analyses, O – office.

Variable Category	Variable	Description	Data Source
Site description	Spring name, country, state/province, county	Unique Name	O
	Topographic map sheet name	Determined from topographic map	O
	Land unit and detail	Manager (federal, state, private)	O
	Project name		O

	Georeference: information source, datum, UTM zone, device, UTM easting, northing, latitude, longitude, elevation and accuracy (EPE, (m or ft), comments	Details of georeferencing	F
	General location and access	Site access, directions	F
	Date, start time, end time, surveyor's names	Who did the survey, when and for how long	F
	Site sketch map	Hand drawn map or photograph, with scale, orientation, date, observers, landmarks, georeferencing points, photo points	F
	Polygon code description	Identify discrete geomorphic microhabitats	F
	Polygon area; surface type and subtype; slope variability (none, low, medium, high); cardinal aspect (MN or TN); soil moisture, water depth; % composition by surface substrate particle size including organic soils; soil type (wetland delineation, if applicable) and geochemistry; % cover of precipitate, litter, wood; average litter depth; wetted area	Describe the size, unevenness, aspect, and surface covers of the polygon	F/L
	Site description and survey notes	Describe the landscape setting and springs type, and site conditions, including extent and forms of human alteration of the site, at the time of the survey	F
	Photography	Describe details of photographs taken, and indicate photo sites on the sketchmap	F
	Solar radiation budget	Total % seasonal and annual solar flux (SF); sum mean winter, spring, summer, autumn and total annual direct SF and percent	F
	Geographic inventory methods and QA/QC	Analytical and information quality assurance and quality control (QA/QC) and management methods and efforts documentation	F/L/O

Biotic inventory	Aquatic, wetland, and terrestrial plant species inventory	List of species detected, noting endemic and non-native taxa; visual estimation of % cover in each polygon by stratum: ground cover (0-2 m graminoid/herb/non-woody deciduous), shrub cover (0-4 m woody perennial), mid-canopy cover (4-10 m woody perennial), tall canopy cover (>10 m woody perennial)	F/L
	Aquatic, wetland, and terrestrial invertebrate species inventory	List of species detected, noting endemic and non-native taxa; quantitative data collection type, species enumeration, substrate, depth, velocity notes by microhabitat	F/L
	Aquatic, wetland, and terrestrial vertebrate species inventory	List of species detected, noting endemic and non-native taxa, extent of grazing or browsing damage	F/L
	Biotic inventory methods QA/QC	Analytical and information QA/QC and management methods and efforts documentation	F/L/O
Geomorphology	Emergence environment	Cave, subaqueous, subaerial, other	F
	Flow forcing mechanism	Gravity, thermal pressure, etc.	F
	Hydrostratigraphic unit: geologic layer of aquifer, rock type	Describe parent rock and rock type	O,F
	Channel dynamics	Surface vs. springsflow dominance	F
	Source geology and flow subtype	Springs emergence: contact, fracture, seepage, tubular	F
	Sphere of discharge and secondary sphere by polygon	Describe the springs type and subtype: Cave. limnocrene, rheocrene, mound-form, helocrene, hillslope spring, gushette, hanging garden, geyser, fountain, hypocrene, paleocrene	F
	Geomorphic QA/QC	Analytical and information QA/QC and management methods and efforts documentation	F/L/O
Flow	Flow consistency	Describe perenniality of flow from long-term records or history, geologic features, dendrochronology, presence of aquatic organisms	F/O
	Flow measurement technique(s), location, mean rate	Replicated flow measurement using techniques described; note measurement location	F
	Flow rate measurement QA/QC	Analytical and information QA/QC and management methods and efforts documentation	F/L/O

Water Quality	Field WQ parameters: Time of day; air and water temperature at source; pH; specific conductance @25µm/cm; concentrations of dissolved oxygen, alkalinity (CaCO3, HCO3)	See Appendix C	F
	Laboratory WQ: Concentrations of base cations and anions, total dissolved solids, H and O stable isotopes (d18OVSMOW and dDVSMOW)	Appendix B	L
	Geochemical WQ methods	Analytical and information QA/QC and management methods and efforts documentation	F/L/O
Cultural resources (see Chapter xxx)	Archeological resources	Archeological surveys, literature review	O,F
	Contemporary cultural resources (TCP, ethnobiology, etc.)	Interviews with tribal elders, botanical inventory, site visits with tribes, literature review	O,F
	Historical resources, histories	Historical surveys, literature review, interviews with elders	O,F
	Cultural methods and results QA/QC documentation	Analytical and information QA/QC and management methods and efforts documentation	F/L/O

Table B2: Equipment List for Level 2 Inventory

Category	Field Equipment Used in Sprigns Inventory and Assessment
All	Background information: site location, description, geohydrology, and previous biotic surveys
All	Datasheets
All	Field computer
All	Information from site description, geology, hydrology, and all biotic surveys
All	Pencils and permanent sample marker (Sharpie)
All	Personal safety gear
All	Protocols document
All	Screwdriver, pliers, and other tools to repair equipment
All	Screwdriver, pliers, and other tools to repair equipment
All	Spare batteries and parts for all equipment
All	Spare batteries and parts for all equipment
All	Topography map of site
All	Ziploc bags
All	Ziploc bags, Whirlpak bags
Biota-all	Field guides (plants, invertebrates, vertebrates, etc.)
Biota-all	Hand lens (10x)
Biota-aquatic	1% chlorox net sterilization in spray bottles, rinse water, and plastic sheet
Biota-invertebrates	Dredge - Petite Ponar
Biota-invertebrates	Ethyl acetate (90%, 1L)
Biota-invertebrates	Ethyl alcohol (70%, 1 L)
Biota-invertebrates	Forceps (2)
Biota-invertebrates	Glass vials 50
Biota-invertebrates	Hand lens 10X
Biota-invertebrates	Killing jar
Biota-invertebrates	Malaise Trap
Biota-invertebrates	Net - aerial sweepnet
Biota-invertebrates	Net - hand (aquarium Net)
Biota-invertebrates	Net - Kicknet
Biota-invertebrates	Net - Surber sampler
Biota-invertebrates	Paper or wax paper envelopes x 50
Biota-invertebrates	UV light trap
Biota-invertebrates	Whirlpak bags 50
Biota-vertebrates	Binoculars

Flow	Baski portable cutthroat flume
Flow	Portable weirs - 45o and 90^{o} (~$300)
Flow	Velocity meter with wading rod and digital display unit
Flow	Volumetric containers with piping/tubing
Flow	Watch with timer
Geography	7.5' Topographic map
Geography	Camera
Geography	Clinometer
Geography	Compass
Geography	Flagging
Geography	GPS unit (and spare as backup)
Geography	Graph paper for sketchmap
Geography	Metric ruler (15 or 30 cm)
Geography	Munsell soil color chart
Geography	Pin flags
Geography	Solar Pathfinder
Geography	Stratigraphic column
Geography and Vegetation	Measuring tape 30 m
Geography and Vegetation	Plant press and newspaper
Geography and Vegetation	Range finder
Geology	Acid bottle
Geology	Geologic hammer
Geology	Rock color chart (or soil color chart)
Geology	Sediment grain size card
Geology	Stratigraphic column
WQ	Acid bottle
WQ	Calibration log book for multi-parameter water-quality meter
WQ	Calibration solutions
WQ	Calibration solutions for pH, dissolved oxygen, and conductivity
WQ	Container for disposal of used ampules
WQ	Filters and spares (0.45 μm water)
WQ	Glass bottles (60 ml; triple acid washed and 1 L DI water rinsed)
WQ	Labeling tape
WQ	Labeling tape
WQ	Latex gloves
WQ	Log book for calibration of multiparameter water quality meter

WQ	Multi-parameter field WQ meter, cables for temperature, pH, DO, SC, and spare and optional (ORP, salinity, nitrate, ammonium, chloride, turbidity) probes
WQ	Nitric acid ampules
WQ	Nitric acid and sulfuric acid ampules, and container for disposal of used ampules
WQ	Poly bottles (250 mL ; acid washed and DI water rinsed)
WQ	Poly bottles (four 60 ml, acid washed and DI water rinsed)
WQ	Sulfuric acid ampules
WQ	Syringes for filtering and spares
WQ	Thermometer (ºC) for air and water

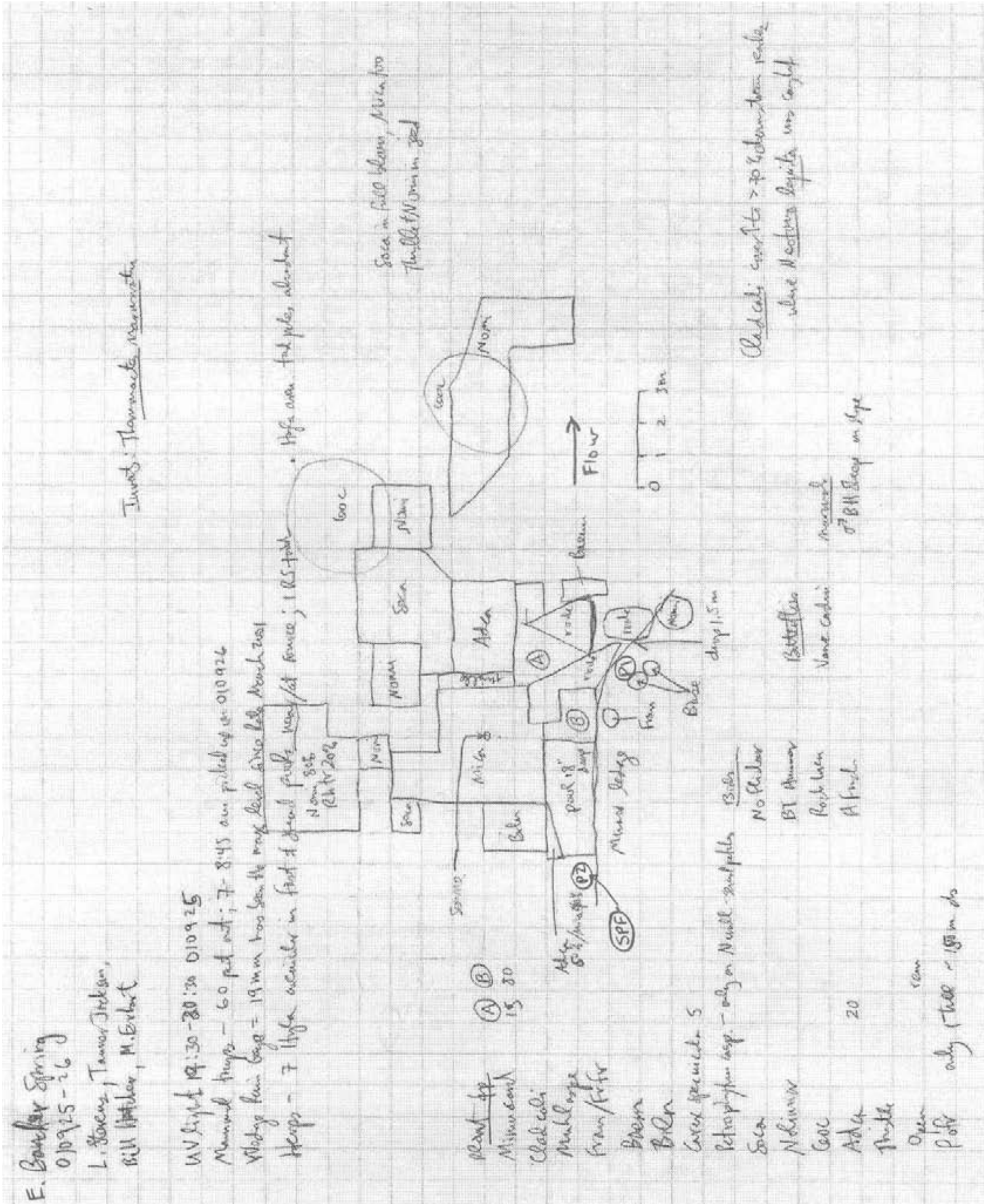

Fig B1: Example of a site sketch map from East Boucher Spring, Grand Canyon National Park, AZ, 15-16 September 2001 (GCWC 2004).

Other Geography Comments: *Site Description* involves a text description of the site in general terms, the springs type, discharge sphere, size, overall aquifer and water quality, and other general information. *Survey Notes* include specific conditions at the springs at the time of the survey, including general ecological condition, conspicuous natural and anthropogenic features or impacts, etc. The *Photo Location* involves the site or camera where the site photographs are stored. The *Site Map Location* involves the site where the sketch map is stored (e.g., in a field book, electronically in a database, etc.). *Comment Boxes* are provided for describing the photographs taken during the site visit.

Site Sketchmap: Once the microhabitats have been identified, the geographer should field map them to scale on a field sketchmap of the site, using graph paper and measuring and describing the dimensions and cardinal orientation of the polygons (e.g., Fig. 1). Declination (the degree difference in magnetic north versus true north) is presented on topographic quad sheets. The sketch map should include the riparian area around the spring and at least 5m past the riparian zone to include upland vegetation. The length and width of the site should be measured with a metric tape. Once the site is outlined, the sketch map should be drawn to include distinct site features, such as: 1) site name, surveyors, date, a measurement bar; 2) a sketch of the site to approximate scale, with flow direction, springs orifice(s), the configuration of associated channels, pools, terraces, and other geomorphic habitats; 4) points at which georeferencing, photograpy, and Solar Pathfinder (see below) measurements were taken; and 4) roads, trails, spring boxes, pipes, troughs, and other constructed features. The sketchmap is scanned into the database, and included along with site photos in the archives. Alternatively, if high resolution ortho-rectified aerial photography is available for the site, the microhabitat polygons and other details can be mapped onto the photograph.

Solar Radiation Budget: The solar energy budget is important to springs because it determines the amount of light available for photosynthesis by springs vegetation, the duration of freezing in winter, and evaporation and relative humidity in the summer months. A Solar Pathfinder (SPF; Solar Pathfinder Inc. 1994) can be used to determine mean monthly duration of direct insolation using the standard protocols defined by Solar Pathfinder, Inc. (1994). The SPF consists of a reflective, transparent dome mounted on a template of the sunpath diagram specific to the latitude of the site. The template contains the percent of solar insolation for half hour intervals between sunrise and sunset for each month. The percent total available solar energy for an average day during any month can be calculated. With a 1-2 minute measurement, the geographer can determine the site's direct solar radiation budget for the entire year. We recommend that three SPF measurements should be made at the source for comparative purposes, and the average reported. The instrument should be calibrated against actual sunrise and sunset times when such opportunities exist at an array of sites. In general, we have found the SPF to be accurate to within approximately 0.5 hr and within 5 m.

The Solar Pathfinder is by far the most efficient and least expensive approach to collection of solar radiation data. Even the finest resolution topographic maps cannot provide information on local topography needed to model microsite insolation, and the SPF can be used to map solar energy budget around the perimeter of larger sites. Alternatively or for Level 3 research, a pyranometer and weather station data may be installed for monitoring temperature, precipitation, humidity in relation to solar radiation.

FLOW MEASUREMENT

Introduction

Systematic hydrological measurements are needed for classifying, understanding, and monitoring spring ecosystems. Hydrological measurements include those for water quantity (discharge) and water quality parameters of the water of a springs ecosystem. Data collected with this protocol will be integrated with other physical and bio-cultural information to clarify the condition and risks to the springs.

We list seven methods to measure springs flow, ranging from standard streamflow cross-section velocity measurement, to the use of portable flumes or weirs, to simple capture, to the measurement of wetted patch area (when flow is unmeasureable). Level I inventory data can help inform the hydrogeologist as to what types of equipment are needed for flow measurement. Table B3 lists the various instruments recommended for the range of discharges which occur in springs. Three additional methods are listed in the procedures (float velocity, static head change, and visual estimation), but are generally be avoided, unless all other instruments are unable to measure discharge. Replicated flow measurements are needed to develop a trustworthy mean value and ascertain uncertainty around the measurement, and we recommend that at least three measurements be made and the average calculated.

Table B3. Discharge magnitudes from Springer et al. (in prep.), ranges of discharge for class, and recommended instruments to measure discharge. Float velocity, static head change, and visual estimation are not recommended and are not included in the table.

Discharge Magnitude	Discharge (gpm)	Discharge (metric)	Instrument(s)
Unmeasurable	No discernable discharge to measure	No discernable discharge to measure	Depression
First	< 0.12	< 10 mL/s	Depression, Volumetric
Second	0.12 to 1.0	10 to 100 mL/s	Weir, Volumetric
Third	1.0 to 10.	0.10 to 1.0 L/s	Weir, Flume
Fourth	10 to 100	1.0 to 10. L/s	Weir, Flume
Fifth	100 to 448.8	10. to 100. L/s	Flume
Sixth	448.8 to 4,488	0.10 to 1.0 m^3/s	Current meter
Seventh	4,488 to 44, 880	1.0 to 10. m^3/s	Current meter
Eighth	> 44,880	> 10. m^3/s	Current meter

Flow

Overview: Measure the quantity of water discharging from the spring. If the discharge of the spring is low (unmeasurable or first magnitude), the discharge measurement may take dozens of minutes and should be initiated early in the site visit. Second to fifth magnitude discharges are relatively quicker and easier to measure. Measurement of sixth to eighth magnitude discharges may take as long as unmeasurable to first magnitude measurements, but can be done anytime during the visit. The name, serial number (if available), and accuracy of the instrument used to measure discharge should be recorded as well as any other important observations. Important observations may include the markers of any recent high discharges, such as high water marks, oriented vegetation or debris on or above the channel or floodplain.

The portable weir plate procedure (USGS - Buchanan and Somers, 1984: p. 57-59): Typically, weirs are used to measure discharge in spring channels which have low to moderate magnitude values of discharge. The weir pushed into a channel of loose material. The weir has a "V" notch, or other regular geometric shape through which all discharge in the channel must be focused. The weir should have a scale on the weir which directly reads discharge. The weir should have a solid plate below the notch which is driven into the loose material of the stream bed material. Weirs do not work in bedrock channels or channels with bed material coarser than fine gravel without a significant amount of channel modification. To use a weir in a bedrock channel or channel material coarser than gravel, the channel must be significantly modified for weir emplacement.

Once placed in the channel, the weir is leveled using a bubble level. The top of the weir plate is made horizontal and the plate must be plumb. Flow through the weir is allowed to stabilize prior to measurement. Gage height is recorded 3 to 5 times over a 3 to 5 minute interval, as appropriate. The mean is calculated from the three replicated and recorded. The volumetric discharge (m^3/s or l/s) is calculated using a standard equation specific to the weir plate being

Fig. B2: The portable weir plate flow measurement procedure.

used. The accuracy of the weir is dependent on the size of the notch in the weir and the resolution of the scale on the weir.

The current meter procedure (USGS - Buchanan and Somers, 1984: p. 31-54): Current meters are used for measuring flow in wadable spring streams or in wide channels or high discharge channels where flow can not be routed into a weir or a flume. Measurement locations are selected in a straight reach where the streambed is free of large rocks, weeds, and protruding obstructions that create turbulence, and with a flat streambed profile to eliminate vertical components of velocity.

In the making of a discharge measurement, the cross section of the channel is divided into 20 to 30 partial sections, and the area and mean velocity of each section is measured separately. A partial section is a rectangle whose depth is equal to the measured depth at the location and whose width is equal to the sum of half the distances of the adjacent verticals. At each vertical, the following observations are recorded on the data sheet, (1) the distance to a reference point on the bank along the tag line, (2) the depth of flow, (3) the velocity as indicated by the current meter. The velocity should be measured at a depth which is 0.6 of the depth from the surface of water in the channel. The discharge of each partial section is calculated as the product of mean velocity times depth at the vertical times the sum of half the distances to adjacent verticals. The sum of the discharges of each partial section is the total discharge.

Fig. B3: The current meter flow measurement procedure.

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

The portable Parshall Cutthroat Flume procedure (Flume) (USGS - Buchanan and Somers, 1984: p. 59-61): Typically, flumes are used in third to sixth magnitude discharge (Table B3, Fig.

B4) springs. Flumes work best in low gradient channels with fine-grained bed material. The wing walls of the flume are pointed upstream in the channel in such a fashion as to focus as much flow as possible through the regular profile of the opening of the flume. The flume requires free fall of water out the downstream end of the flume. The flume is set in a channel of loose material. A bubble level is used to make sure the flume is level. The floor of the upstream section is leveled both longitudinally and transversely. Flow is allowed to stabilize prior to measurement. Gage height is recorded 3 - 5 times over a 3-minute interval. A standard rating curve for the flume is used to translate gage height to discharge. The mean value for discharge (m^3/s or l/s) is calculated and recorded. Accuracy of the instrument is dependent on the scale on the flume. On some occasions, it may not be possible to capture 100 % of the discharge in the flume. If less than 100 % of the discharge is captured by the flume, the percent of flow captured by the flume should be estimated by for each of the 3 to 5 measurements and recorded. A correction to the discharge measurement should be made to account for the percent of discharge not captured by the flume.

Fig. B4: The cutthroat flume measurement procedure.

***The volumetric measurements procedure (USGS - Buchanan and Somers, 1984: p. 61-63)**:* Volumetric measurements are typically used in first and second magnitude discharge (Table B3) springs, where there is a pour off, or other features that allow flow to be easily captured in a volumetric container. A temporary earthen dam is constructed using earth and nonpermeable materials. Water is diverted through the temporary earthen dam with a temporary pipe or constructed channel. Flow is allowed to stabilize prior to measurement. A volumetric container is used to catch discharge from pipe. The time to fill the container is recorded. Flow is recorded 3 to 5 times over a 3 to 5-minute interval, as appropriate. The mean value is calculated (mL/s) and recorded. Accuracy of the instrument is dependent on the accuracy of the volumetric container. A suite of varying size of containers appropriate for first to second magnitude discharge springs should be taken to the field site. When not used for volumetric measurements, the containers can be used to help pack various other field gear used for the rapid assessment.

Fig. B5. The volumetric flow capture measurement procedure.

The float velocity procedure (USGS - Buchanan and Somers, 1984: p. 63): Two cross sections are selected and marked with flagging along a reach of straight channel. The distance between the two sections is measured with the measuring tape. The width and depth of each channel cross section is measured with the tape measure and recorded. Cross section locations are separated to allow for a travel time of >20 sec float time (if possible). A float, i.e., wooden disk(s), is placed in the stream channel and allowed to reach stream velocity before the upstream cross section is crossed. The position of the float relative to the channel sides is noted. The float is timed between the two cross sections. The position of the float is noted as it crossed the downstream cross section. This procedure is repeated 3 to 5 times, as the float is placed at different locations across the channel at the upstream cross-section. The velocity of the float is equal to the distance between the cross sections divided by the travel time. The mean value of surface horizontal velocity (m/s) is calculated. To convert mean surface velocity to mean vertical velocity a coefficient of 0.85 is multiplied by the mean surface velocity. Discharge (m^3/s) is calculated by multiplying the value of mean velocity by the average area of the section of the stream channel measured. This is a method of last choice compared to the more accurate velocity measurement techniques listed above.

The depression/sump procedure: This method is typically used for unmeasurable to first magnitude springs with little to no surface expression of flow. This method is used for relative comparison value of discharge. A depression is constructed in the seep area. The volume of depression is calculated using volumetric calibration or calculation. The volumetric containers used for the volumetric measurement may be used to estimate the volume of the depression. The depression is evacuated, and the time required to fill depression is recorded. This procedure is repeated 3 to 5 times and the mean value is recorded as the measurement.

The static head change procedure: This method may be used for a relative comparison value for change in elevation of standing pools. A metric staff gage is placed in the standing pool and relative gage elevation recorded, or efforts are made to locate and record an existing fixed point in or near standing pool and record vertical distance to pool surface. At a later date, the changes in the static head on the staff gage or fixed point are recorded. This measurement technique is of last choice compared to the more accurate other more accurate methods listed in the protocol and should only be used if necessary.

The visual estimate procedure: Site conditions, such as dense vegetation cover, steep or flat slope, diffuse discharge into a marshy area, and dangerous access sometimes do not allow for a direct measurement of discharge by the techniques listed above. Although visual estimation is imprecise, it may be the only method possible for some springs. Photographs should be taken to record the surface area wetted or covered by water and observations recorded on the datasheet. Also, it should be noted if another method could be recommended for future site visits to measure discharge.

Other flow comments: Subaqueous springs emerge from the floors of streams, lakes, or the ocean floor. Difference methods can be used to estimate flow of larger springs in stream channels. However, measurement in subaqueous lentic settings, such as lake floors or marine settings, may involve measurement of the area and velocity of discharging flow.

WATER QUALITY MEASUREMENT

Field Water Quality Measurement

Overview: Water quality information is determined from field and laboratory measurements. Field parameters include: pH, conductivity (electrical = specific conductance, SC), dissolved oxygen concentration, water temperature, and potentially other parameters that are accessible on the specific multi-parameter field water-quality instruments. Laboratory analyses of samples removed from the field include: alkalinity, major cations and anions, nutrients (nitrogen and phosphate), total dissolved solids, and stable isotopes (oxygen and hydrogen). Field water-quality parameters should be measured prior to collecting laboratory water samples and prior to measuring flow and aquatic biota.

Geochemical methods have been defined by the U.S. Geological Survey and the Environmental Protection Agency. In general: 1) air and water temperature, pH, specific conductance, and dissolved oxygen concentration should be taken using calibrated field instrumentation at the source (not in a convenient spot downstream from the source); 2) at least one filtered 60 mL - 0.5 L water quality sample should be collected in triple acid-rinsed bottles for laboratory analyses of major cations and anions and nutrients; and 3) 1-2 filtered water samples should be collected for stable isotope analyses in triple acid-rinsed 4-10 ml bottles.

Field Velocity Measurements: Field water-quality parameter measurements of specific conductance (mS/cm), pH (pH units), temperature (ºC), and dissolved oxygen (mg/L) should be conducted in a fashion that follows established U.S. Geological Survey and Environmental Protection Agency protocols. An InSitu, Inc. Troll9000 multi-parameter water-quality meter with hand-held Rugged Reader and quick calibration solutions can be used. This instrument is rugged, light-weight, and extremely portable for the rapid assessment procedures. This instrument has the additional capability (by adding additional probes) to measure oxygen reduction potential, salinity, depth, barometric pressure, nitrate, ammonium, chloride and turbidity if these field parameters are deemed necessary at a specific spring. Alternatively, a Hydac electrical conductivity (EC), pH, and temperature meter, or equivalent (e.g., a Hydrolab™) can be employed for field measurements.

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

Field water-quality measurements from flowing water sites should be from discharge areas with uniform flow, with stable bottom conditions, and where constituents are mixed along the flow path, as possible (USGS Field Manual chapter A1, 1.2.1.A, p. 2 & 6.0.2 A p.2). Field water-quality measurements from still water or pooled sites are taken using a vertical profile and spatially distributed to accommodate each site (USGS Field Manual chapter A1, 1.2.1.A, p. 2 & 6.0.2 A p.1).

The depth of the still-water or pool should be measured and water-quality parameters should be measured at a minimum of 3 depths at ¼, ½, and ¾ of the depth. After the measurement location is selected, allow water to contact the instrument sensor for one minute or until pH, dissolved oxygen, EC, and temperature values stabilize and then record the measurements. The federal protocols manual can be viewed or down-loaded from the Internet at http://water.usgs.gov/owq/fieldprocedures.html.

Laboratory Water Quality Measurement

Sample Collection: Prior to fieldwork, wash at least one 60 mL and one 4 mL polyethylene bottles in 10% HCl acid three times and rinse with deionized water. After washing, allow them dry and then cap them. Label each bottle with a distinctive color of labeling tape to distinguish treatments. Record the site, date, and treatment on the label.

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

Samples should be stored on ice in the field but not frozen, and transferred to a refrigerator and stored at 4ºC, and sent to a certified analytical laboratory for processing. PO_4^{-3}, NO_3^-, and NH_3 should be processed within 48 hours of collection, following EPA standards, while cation and anion analyses should be undertaken within 28 days. Analysis should be conducted using automated color imagery techniques or other appropriate analytical equipment (Table B4). Flame atomic absorption spectrophotometry should be used to analyze Mg^{+2}, Ca^{+2}, and Na^+ after 40 days of collection. Ion chromatography is used to analyze PO_4^{-3}, NO_3^-, and NH_3 40 days after collection (Table B4).

Table B4: Chemical parameters, instrument type, detection limit, sample preparation and recommended sample handling times.

Chemical Parameter	Instrument	Detection Limit	Sample prep	Handling Time
18-Oxygen (^{18}O)			No filtering or preservation required	
2-Hydrogen (^2H)			No filtering or preservation required	
Nitrogen – Ammonia (NH_3)	Tehnicon Auto Analyzer, or comparable	0.01-2mg/l NH3-N	Filtered, 4°C H_2SO_4 to pH<2	28 days
Phosphorus (PO_4^{-3})	Tehnicon Auto Analyzer, or comparable	0.001-1.0 mgP/l	Filtered, 4°C H_2SO_4 to pH<2	28 days
Nitrate-Nitrite (NO_3^-)	Tehnicon Auto Analyzer, or comparable	0.05-10.0mg/L NO_3-NO_2-N	Filtered, 4°C H_2SO_4 to pH<2	28 days
Chloride (Cl^-)	Ion Chromatograph	0.5mg/L and higher	Filtered, no preservation required	40 days
Sulfate (SO_4^{-2})	Ion Chromatograph	0.5mg/L and higher	Filtered, no preservation required	40 days
Calcium (Ca^{+2})	Flame Atomic Absorption Spec.	0.2-7 mg/L	Filtered, HNO_3 to pH<2	40 days
Magnesium	Flame Atomic	0.02-0.5 mg/L	Filtered, HNO_3 to	40 days

(Mg^{+2})	Absorption Spec.		pH<2	
Sodium (Na^{+})	Flame Atomic Absorption Spec.	0.03-1mg/L	Filtered, HNO_3 to pH<2	40 days

GEOMORPHOLOGY

Hydrostratigraphic Unit Description

The name and rock type of the source stratum/strata for the spring should be described. Prior to visiting the site, the geologist should review the literature on local geology and structure. If a stratigraphic column or geologic map exists, it should be reviewed prior to site visit and taken into the field. Because the source may not be evident, it is important to walk upstream in a channel till the origin of the flow is discerned.

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

Emergence Environment Description

The environment in which the spring aperture exists varies widely, from the special case of in-cave springs that may or may not afterwards reach the surface, to subaerial emergence in a wide array of geomorphic settings, springs that emerge below glaciers, subaqueous freshwater lentic and lotic settings, on the floor of estuaries, and in a wide variety of marine settings. Following are the various emergence environments. One is to be recorded on the datasheet and any additional descriptions should be noted.

Cave **–** A special case, not usually considered as a spring because it may only be indirectly exposed to the atmosphere

Subaerial, by geomorphic setting- Above-ground emergence - note geomorphic setting (e.g., floodplain, prairie, piedmont, canyon floor or wall, mountainside, etc.)

Subaqueous-lentic freshwater- Aquatic emergence into pond or lake **–** note substratum (organic ooze, silt, sand, rock)

Subaqueous-lotic freshwater- Aquatic emergence into a stream or river- note substratum (organic ooze, silt, sand, rock)

Flow Forcing Mechanisms

The forces that bring water to the surface may not be evident on a single visit, or without information on subsurface water from surrounding wells. If the forces that bring water to the surface are evident, they should be described. Typically, most springs are gravity fed. Gravity-fed springs systems direct groundwater flow down gradient within the aquifer. Artesian springs discharge water under pressure, or may issue from an aquifer that has an upper confining layer, subjecting the flow to fluid pressures in excess of the pressure due to gravity at the point of discharge. Thermal springs emerge when groundwater comes in contact with magma or geothermal warmed crust, and is forced sometimes explosively as in geysers, to the surface. Some springs do not flow and therefore are not subject to pressurized discharge, while other springs may have multiple forcing mechanisms. Anthropogenic factors, such as groundwater loading around large reservoirs, may create forces that also affect springs emergence. One of the following types should be circled with any additional notes recorded. If additional data is needed to determine this information, it should be noted.

Gravity driven springs--Depression, contact, fracture, or tubular springs
Artesian springs- Increased pressure due to gravity-driven head pressure differential
Geothermal springs--Springs associated with volcanism
Springs due to pressure produced by other forces--Springs associated with deep seated fractures
Springs due to pressure produced by anthropogenic forces—Anthropogenic artesian or geyser systems (e.g., hot springs associated with Hoover Dam, Arizona-Nevada)

Source Geomorphology

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

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

Springs Runout Channels

The morphology of the channel should be examined (if a channel exists) to determine if it is spring-dominated or surface-flow dominated. If a channel is spring discharge dominated, the channel often is nearly bank full at baseflow conditions of the spring. If the channel is surface-flow dominated, typically the channel is oversized for the baseflow of the spring. Typically there are two bankfull stages for surface-flow dominated channels; a small, incised channel for baseflow condition, and a larger, wider channel for surface-flow dominated conditions.

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

MICROHABITAT DESCRIPTION

Soils and Physical Microsite Characteristics

Soil moisture, texture, and composition, as well as observations on soil quality and the extent of disturbance (e.g., trampling by livestock, etc.) are recorded on each microhabitat polygon (Schoeneberger 2002).

Soil moisture is visually estimated as the springs-generated moisture in surface soils on a 1-11 scale, ranging from: dry (=1, no soil moisture, soil easily separates), moist (4 = little moisture), damp (moderate moisture), wet (=7, soil easily sticks together), saturated (=9, completely wet, added water does not soak up, but no standing water), and inundated (11, water flowing through soil). Note that a polygon may have combinations of soil moisture categories. ***Percent wet*** is visually estimated percent of the polygon surface that is wet. ***Water depth*** is the maximum water depth on the polygon.

Soil texture is visually estimated from the surface of the soil, and the percent cover of each substrate type is recorded on the datasheet. The soil texture category should be identified using the modified Udden-Wentworth scale: 1) clay, 2) silt, 3) sand (0.1-1mm), 4) pea gravel (1-10 mm). 5) coarse gravel (1-10 cm), 6) small boulders (10-100 cm), 7) large boulders (>1m), 8) bedrock, and 9) organic soil, including peat. Soil color can be

Percent litter cover to the mineral soil (Schoenberger et al. 2002) includes the percent of leaves, twigs, and small owned branches (branches <1 cm in diameter) covering the ground, and should be visually estimated in each microhabitat polygon. Three or more measurements of litter depth should be obtained from different areas within the polygon and used to estimate ***average litter depth*** across the polygon. ***Percent cover of wood*** (branches or logs >1 cm in diameter) also is visually estimated, with the proviso that percent litter cover, percent wood cover cannot exceed 100%.

Percent cover of precipitate is visually estimated. In some cases, precipitate may cover litter and wood, and therefore, percent precipitate, litter, and wood do not necessarily sum to 100 percent.

Dip angle and aspect also are measured and recorded for each geomorphic polygon. ***Dip angle (slope)*** of each vegetation patch should be measured in degrees using a clinometer. ***Aspect*** is the cardinal orientation of each polygon, as measured with a Brunton or a sighting compass, and noting whether the compass has been adjusted for declination (e.g., as magnetic versus true north) and noting that $360^{o} = 0^{o}$.

We regard Clean Water Act wetland delineation as a Level 3 activity; however, it may be conducted if time permits or if a separate, qualified wetlands delineator accompanies the inventory staff.

FLORA AND VEGETATION

Overview

All species of plants detected on the site are identified to species level, and nativity. Several individuals or diagnostic portions of unidentifiable plant species should be collected and recorded on the datasheet. Herbaceous plants (i.e. grasses, annual and perennial plants) should be collected in their entirety, including the leaves, stems, roots, and flowers (if possible). Leaves, cones, flowers, and branches, if possible, should be collected from woody species and trees. Plant specimens should be placed in a plant press and each should be marked with collection data and a unique collection number on the bag and on the data sheet.

Algae, liverworts, mosses and other non-vascular plants also can be collected for taxonomic identification. Algae are best preserved by placing the sample in filtered, buffered 3% glutaraldehyde 3%, neutralized to pH 7 with NaOH.; or in Lugol’s solution or other staining preservatives. Mosses and vascular plants should be hand collected and placed in an envelope for dry preservation. In the laboratory, the bags should be dried in an oven at 60ºC for 48 hours or air dried for preservation.

Vegetation is visually estimated as percent cover (VE%C), which is recorded for each species on each geomorphic microhabitat polygon (Bonham 1989). Species taxonomy and nativity are recorded in a look-up table that provides a regional compilation of springs plant taxa, and which greatly reduces taxonomic typographic errors. Vertical structure in each polygon is documented in five strata: aquatic (including algae and emergent taxa), ground cover (annual herbaceous and graminoid), shrub cover (0-4 m perennial woody), middle canopy (4-10 m tall woody), and tall canopy (>10 m tall woody). Moss, lichen, cryptobiotic crust, and other non-vascular (NVT) taxa cover often provide nursery substrate, and NVT cover will be tallied separately. Plant cover estimates typically vary by 10-20% among observers. A given plant species may occupy several strata: for example a tree species may be present as seedlings (ground cover), and the mature tree may occupy shrub, mid- and tall-canopy space. The SIP database distinguishes these “stratum taxa” from total species richness in the automated vegetation reports.

VE%C is inherently subject to inter-observer bias, with only coarse levels change detection anticipated. We generally find that VE%C is more accurate with discussion between the field biologist and the bio-assistant, and when crew training and membership is consistent among inventories. VE%C by polygon, stratum, and nativity is summarized in an automated report within the SIP database, saving a great deal of analytical and reporting time. Plant species that cannot be determined on-site by the staff biologist should be collected, labeled as to site, date, and polygon, and returned to the laboratory for identification. Aquatic plant species often are best pressed on wax paper to prevent the specimen from sticking to the pressing sheets.

Vegetation Relevance to Ecological Condition

Vegetation cover estimates are used to frame SEAP analysis of habitat extent, quality, and function (see SEAP section, below). Along with the extent of non-native species cover and species richness, the SIP database automatically reports many components of habitat structure and function based on vegetation characteristics of the site. When a large number of springs have been analyzed for vegetation, it will be possible to refine our understanding of the complex interactions among soils, aspect, elevation, climate, and biogeographic affinity on springs vegetation and habitat structure. While the first Level 2 site visit will document the majority of plant species present, Grand Canyon Wildlands Council (2004) reported that several seasonal site visits during different seasons were needed to detect >90 percent of the macrophytic species present, particularly facultative riparian taxa and winter and spring annuals.

FAUNA

Overview

All aquatic and terrestrial macrofauna detected at the site should be documented. We recommend that the biologist spend 30 minutes at the site prior to the arrival of other team members to observe wildlife or sign that may subsequently disperse or be obliterated by other team members. Rare species often require active searching of specific microhabitats (e.g., Springsnails in the orifice; *Psephenus* beetles on the undersides of large cobbles). Aquatic and terrestrial macroinvertebrate detection methods vary considerably among taxa and are described separately below.

Aquatic Macroinvertebrates

Aquatic macroinvertebrates should be collected from each aquatic habitat and substrate present at a spring. The aquatic substrates and habitats should be identified at a site prior to collection and include: silt, sand (<2mm), gravel (2-5mm), cobble (5-30mm), boulder (>30mm), bedrock, aquatic vascular vegetation, and algae. Springs often have limited habitat and substrate; therefore, all the categories mentioned above may not be present.

The appropriate quantitative (where possible) method(s) to collect aquatic macroinvertebrates should be selected for each specific habitat type. Two to five individuals or diagnostic portions of all aquatic macroinvertebrates should be collected for taxonomic identification.

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

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

Spot Sampling: Spot-sampling is a qualitative measure used for sampling shallow flows, vegetation, standing water and pools, and free-floating macroinvertebrates. A hand-net (aquarium net) or D-frame net can be used to sweep up free-floating macroinvertebrates and those in the water. These macroinvertebrates are typically observed from the water's surface. A D-net or seine also can be used to collect macroinvertebrates.

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

After collection, aquatic macroinvertebrates transferred to a whirlpack bag or a vial into 80% EtOH for sorting and enumeration in the laboratory. Be sure that the concentration of EtOH is sufficiently high as water from the sample will further dilute the sample. Samples collected by quantitative methods will include a mixture of substrate and macroinvertebrates, and coarse materials should be removed from the sample promply. The bag or vial should be labeled with the site name, date (yymmdd), and substrate or habitat affiliation with a permanent marker, and an indelible ink label with the information also should be placed within the bag or vial. Samples will be sorted and enumerated in the laboratory. If genetics analyses are foreseen for samples, specimens should be preserved in at least 90% EtOH in sterile, inert containers, and stored in a dark, refrigerated environment.

Mosquito larvae (Culicidae) and other larval holometabolous forms (where the final molt of the macroinvertebrate is the pupal stage transforming into an adult) should be collected alive, and placed in a zip-lock bag filled with stream water. If time back to the laboratory is delayed, these macroinvertebrates should be placed in a damp paper towel inside an open bag. Label the bags with the site name, date, substrate or habitat affiliation, species name, and state that it is a live sample. These macroinvertebrates can be reared in the laboratory until the adult stage is reached for identification. For detailed rearing instruction consult Borror et al. (1989) and Merritt et al. (2008).

Hydrobiidae springsnails and other aquatic snails are of particular interest as indicators of flow perenniality, and because many taxa are endemic to individual springs.

Sada 2005 (Appendix B:44-45) describe the details of how to collect and preserve these taxa.

General nocturnal aquatic sampling may provide a very different view of the springs invertebrate assemblage, as many taxa (e.g., leeches, Turbellaria, Annelida, and many aquatic Hexapoda) are nocturnal and unlikely to be encountered during the daytime. The use of ultraviolet light traps and Malaise traps will result in the capture of many taxa not detected during the daylight hours, and UV trapping in particular may be the only technique to capture adult Trichoptera.

Laboratory Macroinvertebrate Analyses*:* In the laboratory, aquatic macroinvertebrate specimens will be separated from the organic material and substrate collected by quantitative methods. Once separated, specimens will be initially sorted into morpho-taxa and identified to order. Terrestrial macroinvertebrates should be pinned or transferred to separate envelopes, and aquatic macroinvertebrates should be transferred to individual vials with 70% ethyl alcohol distinguished by order. Subsequently, macroinvertebrates should be identified to lower taxonomic levels (preferably to the genus or species level) by an accredited taxonomist or by using North American taxonomic keys (Thorp and Covich 1991, Merritt et al. 2008). If quantitative samples were collected, macroinvertebrates should be enumerated and density (species/m^2) should be calculated.

Each specimen should be accompanied with a label with the site name, date, substrate or habitat affiliation, taxonomic name of the macroinvertebrate, and the first name initial and full last name of the collector. Final labels for macroinvertebrates should be typed and printed on fairly stiff white, waterproof, paper, not larger than 6 x 19 mm (Borrer et al. 1976). Labels should be placed below the macroinvertebrates for pinned specimens and inside vials for alcohol preserved specimens. Specimens should be properly curated and databased.

Terrestrial Macroinvertebrates

Overview: Documenting the use of the springs by terrestrial fauna is important for understanding the ecological role of the springs to the surrounding ecosystem. A wide array of terrestrial macroinvertebrate taxa may be present, including: aerial adults of taxa with aquatic larvae (e.g., Odonata, Plecoptera, Trichoptera, Lepidoptera, many Diptera taxa); semiaquatic ochterid, gelastocorid, and saldid waterbugs; amphibians, reptiles, and some bird and mammal species; and fully terrestrial wetland-riparian carabid ground beetles, cicindelid tiger beetles, and upland reptiles, birds and mammals. Wildlife use of springs can be surprisingly intensive: Grand Canyon Wildlands Council, Inc. (2002) reported 35 bird species, some in great abundance, watering at a remote spring on the North Rim of Grand Canyon during a single 2-hr Level 2 site visit, and commonly 2- to 5-fold higher avian density and species richness at springs as compared to the surrounding uplands. Although many terrestrial vertebrate species may be detected during a single site visit, developing a relatively complete list of the species present will requite numerous visits at different times of the year, which should be one of the goals of Level 3 efforts. Expert entomological guidance typically is required for the preparation of various aquatic and wetland insects. For example, the mandibles of cicindelid tiger beetles should be spread to permit ease of identification. Herpetofaunal detection and monitoring should generally conform to the data standards and protocols of the U.S.

Geological Survey (for a review of methods see Dodd 2007), the U.S. Army Corps of Engineers (Guilfoyle 2010), and the National Forest Service multiple species inventory and monitoring protocols (http://www.fs.fed.us/psw/programs/snrc/featured_topics/msim/documents/msim_chapter_8_terrherps_fnl.pdf).

Collection Protocols: Prior to macroinvertebrate collection, add two tablespoons of 90% ethyl acetate to the kill jars and fasten lid. Ethyl acetate should be added every four hours to maintain strength. Macroinvertebrates should be collected from all terrestrial habitat types within the spring vicinity, using the appropriate method. The appropriate equipment used to collect macroinvertebrates will depend on the substrate type. Two to five individuals or diagnostic portions of all macroinvertebrates encountered should be collected, and all taxa observed are recorded on the datasheets. Some techniques are described below.

Sweep Net Technique: Collection on vegetation, including small trees, shrubs, grass, and annual plants are conducted using the sweep net technique (Borrer et al. 1976). To collect macroinvertebrates, swiftly swing the net back and forth through vegetation for 1min. Each vegetation type should be collected separately and recorded on the datasheet. Once macroinvertebrates are collected, shake them to the bottom of the net.

Spot Collecting: Spot collecting is used for macroinvertebrates that cannot be collected using the sweep net technique, such as those found on: tree trunks, rocks, under logs and fallen branches, in leaf litter, and in flight. To find macroinvertebrates using the spot sample technique investigate tree trunks, turn over rocks, and fallen logs and branches, and sift through leaf litter. Macro-invertebrates found on substrates can be collected with forceps and aerial macroinvertebrates (i.e. butterflies, dragonflies, and damselflies) can be captured with a sweep net.

Beating Sheet: This method is useful for collecting invertebrates that occur on vegetation, but drop of the plant when disturbed (i.e. adult stoneflies (Plecoptera) and caddisflies (Trichoptera). Place a 1 mm or finer mesh insect net under a bush or tree, and tap the branches of the vegetation until the macroinvertebrates fall from the vegetation onto the net (Borrer et al. 1976).

Once captured, transfer macroinvertebrates to a kill jar to relax the body parts. Macroinvertebrates may be removed from the sweep net by grasping the end of the net where the macroinvertebrates have accumulated, and placing the opening of the net over the opening of a kill jar and tapping them in. Also, macroinvertebrates may be removed using forceps and are placed in the kill jar. Once in the killing jar, screw on the lid until the macroinvertebrate does not move (15 min.). Once relaxed, macroinvertebrates should promptly be processed and preserved to prevent them from becoming brittle. Specimens should be preserved with the appropriate method, such as mounted and pinned, dry preserved, or preserved in 70% ethyl alcohol. Record the methods used to preserve the macroinvertebrates in the comments section on the datasheet.

As with nocturnal of aquatic mcroinvertebrates, nighttime sampling will produce a very different invertebrate assemblage. The use of ultraviolet light traps and Malaise traps will result in capture of many taxa not detected during the daylight hours.

Mounting Macroinvertebrates: Hard bodied macroinvertebrates (especially mosquitoes and mirid bugs) should be mounted on insect pins (size 2-3) in the field for identification and preservation. Consult Borror et al. (1989) for detailed mounting and pinning instruction. Pinned specimens should be placed in sealable invertebrate boxes or shelves. Hard-bodied macroinvertebrates can also be preserved dry in a small paper envelope.

Preservation in Ethyl Alcohol: Soft-bodied terrestrial macroinvertebrates and mollusks should be preserved in a capped vial filled with 70% ethyl alcohol, taking care that the overall concentration of preservative does not fall below 70% due to dilution from wet specimens. Macroinvertebrate specimens and envelopes should be individually labeled with the site name, site identification number, date (yymmdd), affiliated habitat, species name, and collectors first name initial and complete last name (i.e. J. Doe). Labels for pinned macroinvertebrates should be printed on fairly stiff white, waterproof, paper, not larger than 6 x 19 mm (Borrer et al. 1976), and placed below the invertebrate. Labels should be written on paper envelopes with black permanent marker.

Also record the technique used to capture the macroinvertebrates, the number count of each species observed, and whether the species was collected on the datasheet. Also, record the host plant and habitat affinities for all specimens. Use scientific or common names for the host plants, if possible.

Sterilization of Nets and Other Equipment

All aquatic nets and other aquatic sampling equipment, boots, and other materials that touch springs waters should be sanitized after each site visit to prevent the spread of chitrid fungi and other pathogens among springs and other water bodies. Protocols to prevent the spread of those pathogens include: spray-application of a $\geq$1% chlorox solution to aquatic equipment and boots; rinsing off the chlorox solution; and properly disposing the rinse solution.

SOCIOCULTURAL INVENTORY

Many springs play important roles in local and regional socioeconomics, and we suggest that documentation and archival of such information is likely to be useful in enhancing springs stewardship. Tribal cultural information about springs is often sensitive and therefore should be collected and compiled by the tribal cultural office, and archived in the database in protected layers.

The categories of sociocultural information indicated on the cultural inventory field data sheet were assembled through interviews of water, natural, and cultural resource departments of several Native American Tribes. These variables include a wide array of ethno-environmental, economic, and religious topics. The form provided in the database provides a means of documenting (through check-boxes) which components, processes, and characteristics are important at individual springs. Those elements can be documented and archived in more detail in the comments boxes and multiple forms of media can be appended to the database, including interviews, photographs, and videography. This form provides the springs stewards with a means of archiving information that may otherwise be at risk of loss due to the passage of time.

Data QA/QC

The crew leader has responsibility for assuring that all field data have been collected, and that the field data are properly stored and transferred to the laboratory for data entry. The primary responsibility for data accuracy and entry should be fall to the field technician(s) who collected the data. They should promptly enter field data into the SIP database upon return to the laboratory. All field data should be preserved in electronically scanned or hard copy formats. All data entry should be overseen and checked by the project supervisor or by the information manager. Data entry errors and data checking should be documented and corrected.

Our SIP database is designed to flag outstanding values for many variables and to maximize veracity of the data, but information quality assurance is ultimately the responsibility of the data entry and quality control team. Our SIP database automatically tracks changes to data with a date stamp and a login name. A QA/QC form on the first page allows the project technicians and supervisor(s) to enter their names and the data checking dates, as well as comment fields.

At present, we do not endorse the practice of on-site electronic data entry, as field sheets are more efficient for Level 2 multi-staff team information compilation, and detection of data entry errors is impossible with electronic field recorders. Therefore, we recommend that data entry from field sheets should be conducted by the the field technician(s) in the laboratory promptly after the data are collected, and checked by the project or information manager.

All hard copy documents should be safely archived (scanning is preferable), and should remain available for future reference. If copies are made of original documents, those copies should be verified as being clearly legible. Specimens collected during surveys should be prepared and curated according to professional museum standards, and identified by qualified experts.

Page ______ of _________ OBS____________

General

Spring Name___________________________ Country____ St/Prov_______ County_______________________

Quad_________________ [1]Land Unit_____________ [2]Land Unit Detail_____________ Project_____________

Access Directions

Georef

Georef Source_____________ Datum______________ UTMZone_______ Device_________________________

UTM E__________________ UTM N__________________ Lat__________________Long__________________

Elev______ EPE______ feet or meters? Georef Comments____

Survey

Date__________________ Begin Time_______________ End Time________________

Surveyor's Names____

Microhabitats

Code/Description	Area (m^2)	[3]Surf Type	[4]Sub-Type	[5]Slope Var	Aspect	Slope Deg.	[6]Soil moisture	Water dpth(cm)	[7]Substrate %									Precip %	Litter %	Wood %	Litter (cm)	Wet area
									1	2	3	4	5	6	7	8	Org					
A																						
B																						
C																						
D																						
E																						
F																						
G																						

Site Description ____

Survey Notes ____

Images

Photo Location____

Site Map Location____

Image Notes____

Photo #	Description

SPF

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

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

Entered by ______________________________ Date_____________ Checked by ______________________________ Date ________________

Fauna

Spring Name__________________________ Page ______ of _________ OBS____________

Scientific Name	Common Name	No. Ind	Meth-od	Area (m^2)	Rep	A/T	Comments

Entered by _______________________ Date___________ Checked by ________________________ Date _____________

Spring Name__________________________ Page ______ of _________ OBS____________

Flora

Species Name	^{16}Str	A	B	C	D	E	F	G	H	Comments	No. Ind	No. Coll

Entered by __________________________ Date___________ Checked by ___________________________ Date ____________

Spring Name__________________________ Page ______ of _________ OBS____________

Flora

Species Name	^{16}Str	A	B	C	D	E	F	G	H	Comments	No. Ind	No. Coll

Entered by __________________________ Date___________ Checked by ___________________________ Date ____________

Spring Name ____________ Page ______ of ________ OBS ____________

Geomorphology

[8]Emerg Env ____________ [10]Mechanism ____________ Geologic Layer ____________

[8]Detail ____________ [11]Rock Type ____________ [12]Channel Dynamics ____________

[9]Source Geo ____________ [11]Rock Subtype ____________

Polygon	[13]Discharge Sphere	[13]Secondary Discharge	Comments

Water Quantity

[14]Flow Consistency ____________ [15]Measurement Technique ____________ Flow Rate (Mean) ____________

Location of Measurements ____________

Discharge Comments ____________

Current Meter l/s m/s other_____

Cell	Distance	Width	Depth	Reading

Flume l/s m/s other_____

Point	Flume Size	Measurements					Avg Stage	% Flow

Volume l/s m/s other_____

Container Size ____________

Point	Measure #	Time to Fill

Weir l/s m/s other_____

Point	Weir Size	Measurements				

Entered by ____________ Date ____________ Checked by ____________ Date ____________

Water Quality

Spring Name__________________________ Page ______ of _________ OBS____________

Measurement Device(s)_________________________________ Date Last Calibrated________________ Air Temp ____________

Collection Location/Comments____

____

Field Measurements

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

Collected for Analysis

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

Entered by ____________________________________ Date_____________ Checked by __________________________________ Date ________________

SEAP

Spring Name ______________________ Date ______________ Obs ______________

Information Source ____

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

Notes:

Entered by ______________________ Date ________ Checked by ______________________ Date ____________

1 Georeference Source
GPS
Map
Other

2 Land Unit
BLM
DOE
NPS
Private
State
Tribal
USFS
Other

3 Surface Type
AU Adjacent Uplands
BW Backwall
C Cave
CH Channel
CS Colluvial slope
HGC High Grad. Cienega
LGC Low Grad Cienega
MAD Unfocused Madiculous
Org Organic Ooze
P Pool
PP Plunge Pool
SB Sloping Bedrock
SM Spring Mound
TE Terrace
TU Tunnel
Oth Other

4 Surface Subtype
CH Riffle, Run, Margin, Eph
TE LRZ, MRZ, URZ, HRZ
UPL,LRZMRZ,LRZURZ

5 Slope Variability
Low, Medium, High

6 Soil Moisture
Dry
Dry-Moist
Moist-Dry
Wet-Dry
Moist
Saturated-Dry
Wet
Saturated-Moist
Wet-Saturated
Saturated
Inundated

7 Substrate
1 clay
2 silt
3 sand
4 fine gravel
5 coarse gravel
6 cobble
7 boulder
8 bedrock
Organic Matter

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

9 Source Geomorphology
Contact Spring
Fracture Spring
Seepage or filtration
Tubular Spring

10 Flow Force Mechanism
Anthropogenic
Artesian
Geothermal
Gravity
Other

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

12 Channel Dynamics
Mixed runoff/spring dominated
Runoff dominated
Spring dominated
Subaqueous

13 Discharge Sphere
Cave
Exposure
Fountain
Geyser
Gushet
Hanging Garden
Helocrene
Hillslope
Hypocrene
Limnocrene
Mound-form
Rheocrene

14 Flow Consistency
Dry Intermittent
Erratic Intermittent
Perennial
Regular Intermittent

15 Measurement Technique
Current meter
Weir
Cutthroat flume
Other

16 Cover Codes
GC Ground Cover
SC Shrub Cover
MC Midcanopy Cover
TC Tall Canopy Cover
AQ Aquatic Cover