Appendix A: Springs Inventory and Assessment Protocols

SKY ISLANDS ALLIANCE
SPRINGS INVENTORY AND ASSESSMENT
TRAINING MANUAL

SPRINGS ECOSYSTEM INVENTORY AND ASSESSMENT PROTOCOLS
VERSION 2.0

DEVELOPED FOR THE SKY ISLANDS ALLIANCE
SPRINGS ASSESSMENT WORKSHOP
APRIL 21-22, 2012, TUCSON, ARIZONA

BY

SPRINGS STEWARDSHIP INSTITUTE
MUSEUM OF NORTHERN ARIZONA
3101 N. FT. VALLEY RD.
FLAGSTAFF, AZ 86001

Springs Stewardship Institute
Improving the health and management of springs

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DAY 1: SATURDAY 20 APRIL 2012: 9:00 A.M. TO 5:00 P.M.

INTRODUCTION

- Sky Island Alliance
- Agua Caliente County Park
  - History of the Park
- Workshop Participants
- Overview of workshop
  - Housekeeping, logistics, etc.

WHAT AND WHERE ARE SPRINGS?

- State, national, global

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- Springs as cultural-biodiversity hotspots
- Springs as evolutionary theatres
- Human threats to springs

SPRINGS ECOSYSTEM ECOLOGY

- Conceptual Model
- Applications to Improved Stewardship

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- Inventory approaches – 3 levels
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  - Level 2 – detailed inventory and assessment
  - Level 3 – long-term studies

SIA hybrid Level 1 and Level 2 Springs Inventory

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  - Geography
  - Sphere of discharge
  - Microhabitat description
  - Site sketch mapping
  - Soils description
  - Solar radiation budget
- Flora and vegetation
- Fauna
- Geology and Geomorphology
  - Geologic context
  - Geomorphology
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- Categories and subcategory scoring
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  - Habitat
  - Biota
  - Human influences
  - Administrative context
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- Conduct Level 1 inventory and SEAP

Conclude at 5:00 p.m.

DAY 2: SUNDAY 21 APRIL 2012: 9:00 A.M. TO 5:00 P.M.

Roy P. Drachman Agua Caliente County Park

INTRODUCTIONS
REVIEW OF PREVIOUS DAY'S TRAINING
QUESTIONS AND REFINEMENTS

SITE VISIT 2: AQUA CALIENTE SPRINGS

Conduct Level 1 inventory and SEAP

BREAK: 10 MINUTES

Reconvene in classroom and debrief

LUNCH: 45 MINUTES

SITE VISIT 3: LA CEBADILLA CIENEGA

Conduct Level 1 inventory and SEAP
Debrief in field

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Conduct Level 1 inventory and SEAP
Debrief in field

CONCLUDING COMMENTS

CONCLUDE AT 5:00 P.M.

CHAPTER 1: SPRINGS ECOLOGY AND STEWARDSHIP— AN INTRODUCTION

Although they are among the most biologically and culturally important and highly threatened ecosystems on Earth, springs are poorly studied and inadequately protected (Stevens and Meretsky 2008). Most springs are relatively small size, yet they support at least 16% of the endangered animals in the United States, as well as untold thousands of rare or highly restricted species. Emerging in many forms, springs are windows into the Earth, and some of the most sensitive indicators of global climate change. Springs are also sites of enormous cultural significance to indigenous cultures.

Very little research has been focused on springs ecosystems. Until recently there has been no systematic effort or methodology for comprehensive eco-assessment. Although there have been recent efforts to develop a more consistent terminology, classification, and methodology, these have not yet been widely accepted. As a result, existing information is often minimal, fragmented and largely unavailable to researchers, land managers, and conservation organizations.

Due to the lack of information and attention to these ecosystems, many springs have been lost through poor groundwater and land use practices, with estimates in some landscapes exceeding 90 percent. This loss of springs habitat constitutes a global environmental crisis. However, if the supporting aquifer is not impaired, springs ecosystems can be relatively easily and inexpensively rehabilitated or restored.

The need for improved stewardship of springs is widely recognized, not only in arid regions but throughout the world. They are of concern to all who manage springs and care about stewardship of critical natural and cultural resources.

The Springs Stewardship Institute is working to improve communications among springs managers to improve understanding and management of springs, and the potential for collaboration and partnership. Our goal is to focus discussion on springs stewardship by sharing information and by presenting technological tools that support efforts to understand the complex ecology of springs. We also conduct research, training workshops, and coordinate with other organizations, agencies, Tribes, and researchers who are trying to locate, study, and protect these critical endangered ecosystems.

Spheres of discharge of springs

Abraham E. Springer · Lawrence E. Stevens

Abstract Although springs have been recognized as important, rare, and globally threatened ecosystems, there is as yet no consistent and comprehensive classification system or common lexicon for springs. In this paper, 12 spheres of discharge of springs are defined, sketched, displayed with photographs, and described relative to their hydrogeology of occurrence, and the microhabitats and ecosystems they support. A few of the spheres of discharge have been previously recognized and used by hydrogeologists for over 80years, but others have only recently been defined geomorphologically. A comparison of these spheres of discharge to classification systems for wetlands, groundwater dependent ecosystems, karst hydrogeology, running waters, and other systems is provided. With a common lexicon for springs, hydrogeologists can provide more consistent guidance for springs ecosystem conservation, management, and restoration. As additional comprehensive inventories of the physical, biological, and cultural characteristics are conducted and analyzed, it will eventually be possible to associate spheres of discharge with discrete vegetation and aquatic invertebrate assemblages, and better understand the habitat requirements of rare or unique springs species. Given the elevated productivity and biodiversity of springs, and their highly threatened status, identification of geomorphic similarities among spring types is essential for conservation of these important ecosystems.

Keywords Springs classification · General hydrogeology · Ecology

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Introduction

Springs are ecosystems in which groundwater reaches the Earth's surface either at or near the land-atmosphere interface or the land-water interface. At their sources (orifices, points of emergence), the physical geomorphic template allows some springs to support numerous microhabitats and large arrays of aquatic, wetland, and terrestrial plant and animal species; yet, springs ecosystems are distinctly different from other aquatic, wetland, and riparian ecosystems (Stevens et al. 2005). For example, springs of Texas support at least 15 federally listed threatened or endangered species under the regulations of the US Endangered Species Act of 1973 (Brune 2002). Hydrogeologists have traditionally classified the physical parameters of springs up to their point of discharge (e.g., Bryan 1919, Meinzer 1923), but have paid little attention to springs after the point of discharge where they are more interesting to ecologists, conservation biologists, cultural anthropologists, and recreation sociologists. Classification systems that incidentally include springs have been developed for surface waters (Hynes 1970), wetlands (Euliss et al. 2004), groundwater dependent ecosystems (Eamus and Froend 2006), and riparian systems downstream from the point of discharge (Warner and Hendrix 1984; Rosgen 1996). An integrated springs classification system should include the major physical, biological, and socio-cultural variables. Such a classification system will permit assessment of the distribution of different kinds of springs ecosystems, thereby improving resource inventory and development of conservation and restoration strategies (e.g., Sada and Vinyard 2002; Perla and Stevens 2008).

Alfaro and Wallace (1994) and Wallace and Alfaro (2001) updated and reviewed the historical springs classification schemes of Fuller (1904); Keilhack (1912); Bryan (1919); Meinzer (1923); Clarke (1924); Stiny (1933), and others. Of the previously proposed systems, Meinzer's (1923) classification system has been the most persistently recognized. He included 11 characteristics of springs based on various physical and chemical variables. Although Meinzer's (1923) scheme has been widely used, it is not comprehensive. Clarke (1924) considered three criteria to be most important for springs classification: geologic origin, physical properties, and geochemistry. Other classifications have been developed for specific types of geomorphology such as karst geomorphology

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(free draining, dammed, or confined springs; Ford and Williams 2007) or classification of karst springs by eight attributes—flow duration, reversing flow, conduit type at spring, geology, topographic position, relationship to bodies of surface water, distributaries, recharge, chemistry, culture/exploitation—(Gunn 2004). Springs, particularly those in arid regions, are renowned as hotspots of biological and cultural diversity, and the presence of endangered or unique species and ethnological and historic resources often greatly influences their management. Therefore, ecological and cultural variables also relevant to springs classification include: size, spatial isolation; microhabitat distribution; paleontological resources; the presence of rare or endemic biota; archeological or traditional cultural resources; and a springs' context to surrounding ecosystems. To date, no comprehensive springs classification system has been developed or accepted (Wallace and Alfaro 2001). Many publications related to springs focus on specific regions that have a limited number of types of springs (e.g., Brune 2002; Scott et al. 2004; Vineyard and Feder 1982; Borneuf 1983). For example, because limnocrene springs of Florida are influenced by karst processes, their classification has focused primarily on the type of spring (vent or seep), whether or not it is onshore or offshore, and the magnitude of the discharge (Scott et al. 2004).

In Springer et al. (2008), previous classification efforts were discussed and an integrated springs classification system was presented, with the understanding that testing and refinement of this classification system requires much further work. Springer et al.'s (2008) organizational structure integrates springs inventory data and reiterates nine of Meinzer's (1923) classes, Alfaro and Wallace's (1994) recommendations, and proposed additional ecological and cultural elements. An organizational structure that integrates springs data and reiterated Alfaro and Wallace's (1994) recommendation to develop a global database on springs using this comprehensive classification system is discussed. The criteria used for classification by Springer et al. (2008) include geomorphic considerations (hydrostratigraphic unit, emergence environment, orifice geomorphology, sphere of discharge, channel dynamics), forces bringing water to the surface, flow properties (persistence, consistency, rate, variability), water quality (temperature and geochemistry), habitats (synoptic climate, surrounding ecosystems, biogeographic isolation, habitat size, microhabitat diversity), springs biota (species composition, vegetation, faunal diversity), and springs management and use. Seeps are considered to be low magnitude discharge springs in this classification system.

In this paper, the 12 spheres of discharge of springs of Springer et al. (2008) are described in more detail than was included in their manuscript (Table 1). A text description, a sketch and a photograph of each sphere is included, as is a discussion of how each sphere corresponds to equivalent language used by aquatic ecologists, wetland and riparian scientists, or other specialists to describe springs. For spheres of discharge where it is known, a description of how the spheres of discharge of

Table 1 Sphere of discharge and types of springs (modified from Springer et al. 2008) with examples of known springs and references of descriptions of sphere of discharge

Spring type	Emergence setting and hydrogeology	Example	Reference
Cave	Emergence in a cave in mature to extreme karst with sufficiently large conduits	Kartchner Caverns, AZ	Springer et al. (2008)
Exposure springs	Cave, rock shelter fractures, or sinkholes where unconfined aquifer is exposed near the land surface	Devils Hole, Ash Meadows, NV	Springer et al. (2008)
Fountain	Artesian fountain with pressurized CO_2 in a confined aquifer	Crystal Geyser, UT	Springer et al. (2008)
Geyser	Explosive flow of hot water from confined aquifer	Riverside Geyser, WY	Springer et al. (2008)
Gushet	Discrete source flow gushes from a cliff wall of a perched, unconfined aquifer	Thunder River, Grand Canyon, AZ	Springer et al. (2008)
Hanging garden	Dripping flow emerges usually horizontally along a geologic contact along a cliff wall of a perched, unconfined aquifer	Poison Ivy Spring, Arches NP, UT	Woodbury (1933); Welsh (1989); Spence (2008)
Helocrene	Emerges from low gradient wetlands; often indistinct or multiple sources seeping from shallow, unconfined aquifers	Soap Holes, Elk Island NP, AB, Canada	Modified from Meinzer (1923); Hynes (1970); Grand Canyon Wildlands Council (2002)
Hillslope	Emerges from confined or unconfined aquifers on a hillslope (30–60^{o} slope); often indistinct or multiple sources	Ram Creek Hot Spring, BC, Canada	Springer et al. (2008)
Hypocrene	A buried spring where flow does not reach the surface, typically due to very low discharge and high evaporation or transpiration	Mile 70L Spring, Grand Canyon, AZ	Springer et al. (2008)
Limnocrene	Emergence of confined or unconfined aquifers in pool(s)	Grassi Lakes, AB, Canada	Modified from Meinzer (1923); Hynes (1970)
(Carbonate) mound-form	Emerges from a mineralized mound, frequently at magmatic or fault systems	Montezuma Well, AZ Dalhousie Springs, Australia	Springer et al. (2008); Zeidler and Ponder (1989)
Rheocrene	Flowing spring, emerges into one or more stream channels	Pheasant Branch, WI, US	Modified from Meinzer (1923); Hynes (1970)

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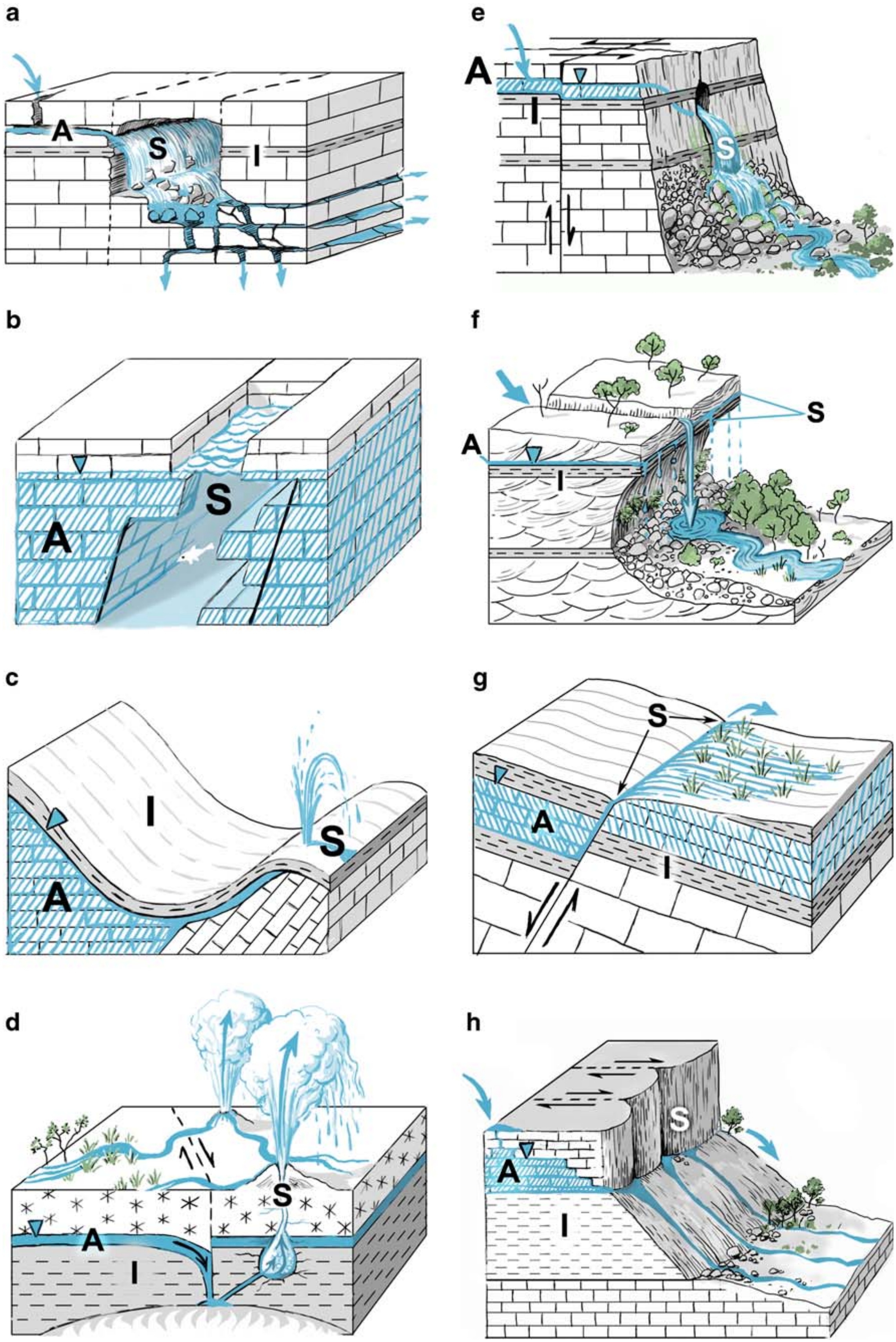

Fig. 1 Sketches of springs spheres of discharge: **a** cave, **b** exposure, **c** fountain, **d** geyser, **e** gushet, **f** hanging garden, **g** helocrene, **h** hillslope, **i** hypocrene, **j** limnocrene, **k** mound form, **l** rheocrene. *A* aquifer, *I* impermeable stratum, *S* spring source. The *inverted triangle* represents the water table or piezometric surface. Fault lines are also shown, where appropriate

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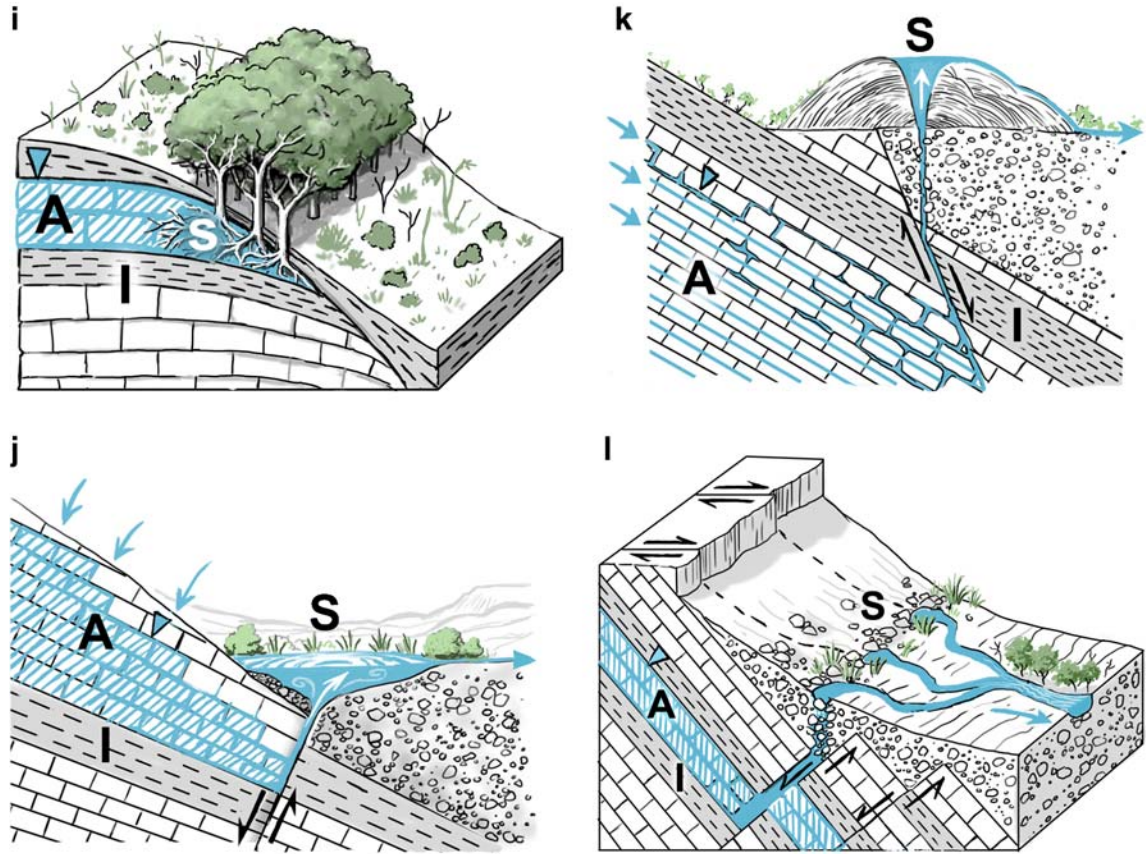

Fig. 1 (continued)

springs create diverse microhabitats which lead to rich and diverse ecosystems is made. Each sphere of discharge has been linked to a conceptual model for springs created by Stevens and Springer (2004) and the array of microhabitats. The success of a future integrated, comprehensive classification system for springs will depend on an inclusive and descriptive set of spheres of discharge coupled with an association of aquatic invertebrates and/or vegetation. However, an insufficient number of comprehensive physical, biological and cultural inventories of springs ecosystems have as yet been conducted to statistically determine these associations.

Background

Conceptual models and classifications systems help organize and categorize complicated natural systems. Various classification systems have been created for various types of hydrological systems. Euliss et al. (2004) created a conceptual framework called the wetland continuum to include factors describing the influence of climate and hydrologic setting on biological communities in wetlands. Although their system is applicable to springs that occur in wetlands, it is not applicable to the many types of springs that do not occur in wetlands. Also, springs only have groundwater discharge, so the wetland continuum concept of Euliss et al. (2004) of recharge is not applicable to springs. Springs occurrence in some geomorphic settings is far more complicated than wetlands (e.g., cliff walls), creating a wide array of microhabitats not observed in wetlands.

Another prominent classification system that includes springs is for groundwater dependent ecosystems (GDE). Three primary classes of GDEs have been proposed (Eamus and Froend 2006). GDE classification tends to focus more on vegetation components of the ecosystem because of the paucity of invertebrate data. The three classes described are: (1) aquifer and cave ecosystems, (2) all ecosystems dependent on the surface expression of flow, and (3) all ecosystems dependent on the subsurface presence of groundwater (Eamus and Froend 2006). As

Fig. 2 Photographs of springs spheres of discharge: **a** cave spring, Kartchner Caverns, Arizona, US, **b** exposure spring, Devil's Hole, Ash Meadows National Wildlife Refuge, Nevada, US, **c** fountain spring, Crystal Geyser, Utah, US—photo by Joel Barnes, **d** geyser, Riverside Geyser, Yellowstone National Park, Wyoming, US, **e** gushet, Thunder River Spring, Grand Canyon National Park, Arizona, US, **f** hanging garden, Poison Ivy Spring, Arches National Park, Utah, US, **g** helocrene, soap hole, Elk Island National Park, Alberta, Canada, **h** hillslope spring, Ram Creek Hot Spring, British Columbia, Canada, **i** hypocrene, 70R mile spring, Grand Canyon National Park, Arizona, US, **j** limnocrene, Grassi Lakes, Alberta, Canada, **k** mound form spring, Montezuma Well, Arizona, US, **l** rheocrene, Pheasant Branch Spring, Wisconsin, US

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Fig. 2 (continued)

will be demonstrated in this paper and by Meinzer (1923) and Hynes (1970) the spheres of discharge of springs and the associated ecosystems with them are more complex than these three classes. Several notable books about springs ecology that have been published (e.g., Botosaneanu 1998 and Stevens and Meretsky 2008) and Odum's (1957) work on Silver Springs in Florida (which laid the groundwork for much of modern ecosystem ecology) also indicate that springs and their associated ecosystems are more complex than the three GDE classes of Eamus and Froend (2006).

Sphere of discharge

The "sphere" into which the aquifer is discharged as described by Meinzer (1923) was greatly simplified by Hynes (1970) into three different classes (rheocrene, limnocrene, helocrene). Springer et al. (2008) expanded these historical schemes to include 12 spheres of discharge of springs, including: (1) springs that emerge in caves, (2) exposure springs, (3) artesian fountains, (4) geysers, (5) gushets, (6) contact hanging gardens, (7) helocrene wet meadows, (8) hillslope springs, (9) hypocrene buried

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springs, (10) limnocrene surficial lentic pools, (11) mound forms, and (12) rheocrene lotic channel floors (Figs. 1 and 2; Table 1). In addition, paleosprings are recognized, which flowed in prehistoric times, but no longer flow (Haynes 2008). Both Meinzer's (1923) original and Hynes (1970) classification schemes become complicated if multiple spheres of discharge are present, or if the spring has a highly variable discharge rate and creates multiple spheres over time. For example, a mound spring may discharge into a limnocrene pool. In the system of Springer et al. (2008), each sphere of discharge should be described for a spring.

Cave

Cave springs are those that emerge entirely within a cave environment and are not directly connected to surface flow (Figs. 1a and 2a). They are most common in karst terrain. Although there are almost an infinite number of different types of karst features (Ford and Williams 2007), engineering geologists have recommended a classification system for karst that includes descriptions of karst classes (juvenile, youthful, mature, complex, and extreme), sinkhole density, cave size, and rockhead (bedrock) relief (Waltham and Fookes 2003). Cave type springs are most likely to occur in the "mature" to "extreme" karst ground conditions of Waltham and Fookes (2003) where the conduits are sufficiently large enough to allow for emergence and in "free draining or dammed" type karst springs (Ford and Williams 2007). The ecosystems of these types of springs have species and habitats characteristic of biologically active caves, such as those described by Elliott (2007).

Exposure

Exposure springs are those in which groundwater is exposed at the surface but does not flow, a form of springs sphere of discharge proposed as new by Springer et al. (2008; Figs. 1b and 2b). These types of springs typically occur in the "dissolution" type of sinkholes (Waltham and Fookes 2003), but could form in other types of vertical conduits into an aquifer. A prominent example is Devil's Hole in Ash Meadows National Wildlife Refuge in Nevada. Because of the unique microhabitats of Devil's Hole, that system supports endemic Ash Meadows riffle beetle (Elmidae: *Stenelmis calida*) and Devils Hole pupfish (Cyprinodontidae: *Cyprinodon diabolis*; Deacon and Williams 1991; Schmude 1999). The plight of the latter species has led to special legal and management protection of the associated aquifer.

Fountain

Fountain springs are cool-water artesian springs that are forced above the land surface by stratigraphic head-driven pressure or CO_2 (e.g., Crystal Geyser; Glennon and Pfaff 2005; Figs. 1c and 2c). Discharge at fountain springs, thus, is not driven by thermal processes, such as geysers, but still require a confined aquifer with water pressurized by CO_2, not heat. Other examples of fountains are cold water, submarine seeps of hydrocarbons, carbonates or brine, which may support dense macrofaunal communities such as those in the Gulf of Mexico slope, Sunda Arc, and 30 other known locations on active and passive continental margins through the world's oceans (Cordes et al. 2007).

Geyser

Geysers are globally rare, geothermal springs that emerge explosively and usually erratically (Figs. 1d and 2d). "A geyser is a hot spring characterized by intermittent discharge of water ejected turbulently and accomplished by a vapor phase." (Bryan 1995) There are over 1,000 geysers worldwide, with nearly half of them existing in Yellowstone National Park, WY, USA. (Bryan 1995). Yellowstone has 600 geysers of which 300 erupt frequently. The only other place in the world with more than 40 geysers is the Kamchatka Peninsula of Russia with approximately 200 geysers (Bryan 1995). There are over 10,000 non-geyser hot springs of various types in Yellowstone, many being other spheres of discharge such as limnocrene and helocrene springs. These thermal waters support unique communities of bacteria (Brock 1994).

Gushet

Gushet springs pour from cliff faces and were proposed as a new, unique sphere of discharge by Springer et al. (2008; Figs. 1e and 2e). They typically emerge from perched, unconfined aquifers, often with dissolution enhancement along fractures. Gushets typically support madicolous habitat, which consists of thin sheets of water flowing over rock faces (Hynes 1970; Table 2). All 13 microhabitat types may be present at gushet springs, leading to very diverse ecosystems. Although they occur prominently in areas with steeply dissected topography (e.g., Vasey's Paradise in Grand Canyon, AZ, USA), they can also occur in regions with more modest topography, such as Wisconsin, US, as long as there is sufficient topographic relief to allow for free-falling flow.

Hanging garden

Hanging gardens are complex, multi-habitat springs that emerge along geologic contacts and seep, drip, or pour onto underlying walls (Figs. 1f and 2f). In the southwestern U.S., they typically emerge from perched, unconfined aquifers in aeolian sandstone units. The hydrogeologic processes that lead to these unique ecosystems also control the geomorphologic processes which shape the rock wall or associated canyons. Generally, three types of hanging gardens are recognized (alcoves, window-blinds, and terraces; Welsh and Toft 1981). In the US, hanging gardens support distinctive assemblages of wetland, riparian and desert plants, including some species (e.g., *Primula* spp.) that occur in indirect light on wet backwalls (Welsh and Toft 1981; Wong 1999; Spence 2008).

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Table 2 Estimated likelihood of occurrence of 13 spring microhabitats at 12 terrestrial spring types reported on the Colorado Plateau (data from Springer et al. 2008 and L. Stevens, unpublished observations)

Spring Type	Springs microhabitats													
	Cave interior	Orifice	Hyporheic	Wet wall	Madicolous	Spray zone	Open-water pool	Spring stream	Low-slope wetlands	Hillslope wet meadow	Riparian	Adjacent dry rock	Adjacent uplands linkage	Average microhabitat diversity of a springs type
Cave	5	1	2	5	3	1	5	5				5	5	3.7
Exposure	5	5		1			5		1	1	1	4	3	2.2
Fountain	1	5	2	3	3	3	3	5	3	3	4	5	5	3.5
Geyser	1	5	2	3	3	3	3	4	3	1	3	5	3	3.0
Gushet	4	5	3	3	3	3	4	5	4	3	5	5	5	4.0
Hanging garden	1	3	2	5	3	4	5	5	2	4	5	5	5	3.8
Helocrene	1	2	3	2	2	1	3	3	5	3	5	2	5	2.8
Hillslope	1	2	3	2	2	1	3	3	4	5	5	3	5	3.0
Hypocrene	1		1						3	4	4	5	5	3.3
Limnocrene	1	5		1	1	1	5	5	3	1	5	3	5	3.0
Mound-form	1	5	2	3	3	1	4	5	3	1	3	5	3	3.0
Rheocrene	3	5		3	3	3	4	5	4	1	5	5	5	3.8
Mean microhabitat frequency across springs types	2.1	3.9	2.2	2.8	2.6	2.1	4.0	4.5	3.2	2.5	4.1	4.3	4.5	—

Occurrence likelihood: *missing* microhabit does not occur at that springs type, *1* very low likelihood of occurrence, *2* low likelihood, *3* moderate likelihood, *4* fair likelihood, *5* high likelihood of occurrence at that springs type. Average diversity values were calculated for within and among springs types

Helocrene

Helocrene springs usually emerge in a diffuse fashion in cienega (marshy, wet meadow) settings (Figs. 1g and 2g). Hynes (1970) distinguished these types of springs as different from the limnocrene type springs described by Bornhauser (1913). What are described as soap holes or mud springs in Alberta also are examples of helocrenes. A soap hole or mud spring is “a part of the land surface characterized by a local weakness of limited extent underlain by a mixture of sand, silt, clay, and water” (Toth 1966). The formation of these springs is similar to that of quicksand. In the semi-arid regions of Alberta, Canada where these occur, groundwater discharge is typically saline, leading to the occurrence of halophytes. Other helocrenes may have fresh water, but low oxygen concentrations, and support species characteristic of wetlands, or they may have thermal waters and primarily support bacteria. Other helocrene springs may have hypersaline water and support marine relict taxa that may occur far inland on continents at great distances from the ocean (Grasby and Londry 2007). The wetland continuum of Euliss et al. (2004) provides further classification of helocrenes.

Hillslope

Hillslope springs emerge from confined or unconfined aquifers on non-vertical hillslopes at 30–60° slopes, and usually have indistinct or multiple sources (Figs. 1h and 2h). Hillslope springs were proposed as a unique sphere of discharge by Springer et al. (2008) because of the diverse array of microhabitats they support (12 of 13 common microhabitat types; Table 2). The diversity of hillslope springs is generally negatively related to the slope gradient, and is strongly influenced by aspect, although those relationships have yet to be rigorously quantified.

Hypocrene

Hypocrene springs are springs in which groundwater levels come near, but do not reach the surface (Figs. 1i and 2i). Discharge from the springs is low enough that evaporation or transpiration consumes all discharge and there is no surface expression of water. In the wetland continuum of Euliss et al. (2004), hypocrene springs would represent a site with the lowest amount of discharge and the lowest inputs of atmospheric water. Investigations of this spring type indicate that they most commonly support halotolerant and drought-tolerant plant species; species that support few herbivorous invertebrates.

Limnocrene

Limnocrene springs occur where discharge from confined or unconfined aquifers emerge as one or more lentic pools (Figs. 1j and 2j). The term was first used by Bornhauser (1913) and then reinforced by Hynes (1970). Limnocrene springs exist in both the wetland continuum and GDE

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classification systems. Although limnocrene springs may have pond and aquatic species, their relatively uniform temperature and chemistry may cause different species to be present than in an adjacent surface-water dominated water body. Montezuma Well in central Arizona is a limnocrene pool in a collapsed carbonate mound spring; the harsh, uniform water chemistry there appears to support the highest concentration of endemic species of any point in North America (Stevens 2007).

Mound form

Mound-form springs emerge from (usually carbonate) precipitate mounds or peat mounds (Figs. 1k and 2k). They are extensively known and described for the Great Artesian Basin in central Australia and from other limited areas of Western Australia, and also in North America (Knott and Jasinska 1998, Springer et al. 2008). Travertine-forming mound springs are often located along active magmatic or fault systems and therefore may be hot, or in the case of "black smokers" hyperthermic, waters, and these systems may emit large volumes of CO_2 from endogenic water sources (Crossey et al. 2008). Mound-form springs often support high numbers of endemic species because of the unique quality of the water or because of their importance as a water source in arid regions where they commonly occur (Knott and Jasinska 1998; Blinn 2008).

Rheocrene

The term rheocrene was first coined by Bornhauser (1913) to describe springs where discharge emerges as flowing streams (Figs. 1l and 2l). Spring-fed streams are also referred to as springbrooks or spring runs. The term was continued as a special habitat of running waters by Hynes (1970) because of the relatively uniform temperature and the de-oxygenated groundwater contribution to the stream. Springer et al. (2008) further recognized that there is a continuum between channels which are springs discharge dominated and those that are dominated by surface runoff. These longitudinal changes in flood-related disturbance, water quality, and geomorphology strongly direct evolutionary processes. Springflow-dominated springs may be sufficiently stable habitats to allow for evolutionary microadaptation, and ultimately speciation, whereas surface flow-dominated systems are typically occupied by weedy, generalist species (McCabe 1998). The different types of channels along this continuum are distinctively different, in turn influencing the types of microhabits that exist in them (Griffiths et al. 2008).

Distribution of spheres of discharge

To date, comprehensive inventories following the protocols of Springer et al. (2006) have been conducted for 244 springs of the Colorado Plateau (Springer et al. 2006) and the Verde Valley of Arizona (Flora 2004) and for 48 springs in Wisconsin (Swanson et al. 2007) in the US. The sphere of discharge was determined for each of the springs on the Colorado Plateau and Wisconsin during those inventories. Although cave, exposure, and fountain springs are known or likely exist in these regions, they have not yet been comprehensively inventoried (Table 3). Geyser springs are not known to exist in those regions. Results of comprehensive inventories of selected springs in the two counties in Wisconsin conducted by Swanson et al. (2007) determined that 40% were helocrene, 38% were rheocrene, 13% were hillslope, 2% were limnocrene, and 8% had other spheres of discharge. Analyses of global distribution of spheres of discharge of springs will not be accomplished until global inventories are conducted and databases constructed.

Threats to springs ecosystems

Springs are among the most threatened ecosystems (Stevens and Meretsky 2008). Primary anthropogenic impacts include groundwater depletion and pollution, alteration of source area geomorphology, and diversion of runout flows. Excessive groundwater pumping presently threatens the flows and biota of springs in the Edwards Aquifer in Texas (McKinney and Watkins 1993), the Verde River watershed in central Arizona (Haney et al. 2008), the hot springs of the Bruneau River in Idaho (US Fish and Wildlife Service 2002), Ash Meadows in Nevada (Deacon and Williams 1991) and the Owens Valley in California (Minckley and Deacon 1991), and elsewhere in the US. Groundwater pollution threatens water clarity of many Florida limnocrene springs (Scott et al. 2004). The Environmental Protection Agency requires that groundwater used for potable water supplies not be exposed to the atmosphere, a management strategy that often results in the capping of springs and obliteration of the source area. Fencing that focuses livestock into source areas, and diversion of runout streams to watering troughs or ponds are two very common practices throughout the Western US. A survey of springs not protected by the US National Park Service in northern Arizona revealed that more than

Table 3 Spheres of discharge of springs inventoried on the Verde Valley of Arizona and the Colorado Plateau (Springer et al. 2006; Flora 2004)

Sphere of discharge	Number inventoried	Percent of total inventoried
Cave	0	0
Exposure	0	0
Fountain	0	0
Geyser	0	0
Gushette	2	0.820
Hanging garden	29	11.8
Helocrene	38	15.6
Hillslope	31	12.7
Hypocrene	1	0.410
Limnocrene	13	5.33
Mound-form	2	0.820
Rheocrene	128	52.4
Total	244	100

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93% were moderately to severely ecologically impaired (Grand Canyon Wildlands Council 2002).

Conclusions

As Brune (2002) noted, “The study of springs is a borderline discipline, because springs are the transition from groundwater to surface water. Hence they have been studied to some extent by groundwater specialists and to some extent by surface-water specialists.” Because springs research is typically conducted by researchers from only one specialty or locality, there has grown a proliferation of different and varying classification and description systems for springs specific to that specialty or locality. This paper is an attempt to allow hydrogeologists to reclaim the description and classification of springs, as well as to inform that classification with information from other disciplines, particularly ecology and evolution. For example, springs in arid regions are hotspots of endemism: the highest concentrations of unique species in North America are found in the pool-forming springs of Ash Meadows (Nevada), Montezuma Well (Arizona), and Quatro Cienegas (Coahuila, Mexico; Stevens and Meretsky 2008).

The 12 spheres of discharge of springs, their descriptions and sketches included in this paper may allow springs researchers from many disparate specialties to share a common language and simplified visualization of these springs types. Also, hopefully, this paper may lead to a more thorough discourse in the literature of the shortcomings of this proposed system, leading to improvement over time. With a common language for springs, it may be possible to better focus limited research, management, and restoration resources onto spring types that are most at risk or most threatened.

When more comprehensive, integrated, springs ecosystems inventories are conducted, including analysis of species distribution among different spheres of discharge, an international database is built, and large-scale statistical analyses are conducted that include the species present along with the sphere of discharge, it will be possible to associate characteristic plant and animal assemblages with those spheres of discharge, and to clearly define a comprehensive springs classification system.

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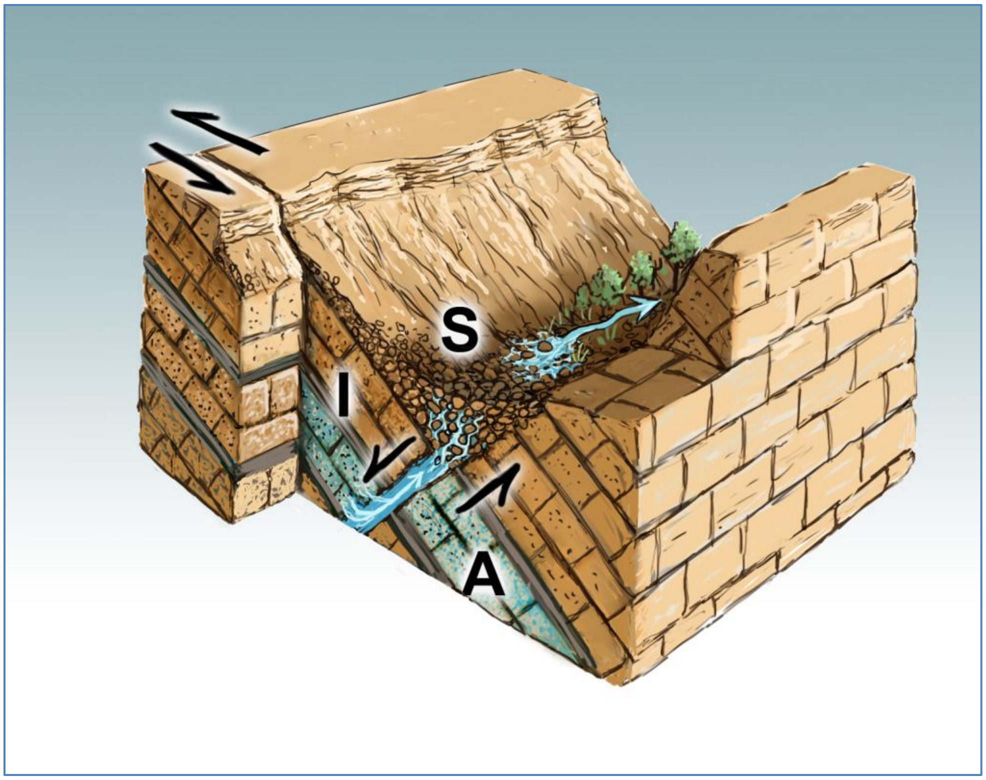


Revised rheocrene spring diagram

CHAPTER 3: A SPRINGS ECOSYSTEM CONCEPTUAL MODEL

Springs ecosystems are among the most structurally complicated, ecologically and biologically diverse, productive, evolutionarily provocative, and threatened ecosystems on earth. Springs are ecosystems in which groundwater reaches the surface through complex, sometimes lengthy, flow paths through subsurface structural, geochemical and geomorphic environments . At their point of emergence, the physical geomorphic template allows some springs to support large arrays of aquatic, wetland and terrestrial species and assemblages, sometimes including cave and hyporheic biota. Many springs serve as paleorefugia, and as long-term stable habitats in which the evolutionary processes of natural selection, isolation, and adaptation (sometimes to extreme environmental conditions) support restricted and endemic species. In ecological time-frames, small isolated springs in arid regions may be tremendously productive, and may provide the only available water and habitat in the landscape for many plant and animal species. From a biogeographical perspective, springs often function as islands of habitat, and may contain paleontological remains that reveal much about changing climates and ecosystem responses over time, particularly in arid regions. Although in temperate regions, the differences between springs and the surrounding uplands may appear to be subtle, studies of Silver Springs in Florida demonstrate the complex interplay between ground and surface water, and aquatic-riparian linkages that characterize springs ecosystem ecology. Many springs emerge in freshwater or marine settings, and recent information on subaqueous springs demonstrates many parallels with those of subaerial springs, including high levels of biodiversity, species packing, productivity and endemism.

Although poorly explored, arid lands springs often appear to function as keystone ecosystems, exerting a vastly disproportionate impact on adjacent ecosystems and regional ecology as compared to non-springs habitats. Several symposia and survey studies of springs have been conducted in the United States; however, springs ecosystem ecology remains rarely studied and poorly known. The scope of most previous work has been on a relatively small suite of physical characteristics of springs (e.g., flow and water quality), individual taxa or biota (e.g., Trichoptera, aquatic snails, aquatic invertebrates, and springs biota in general), or on relatively restricted geographic areas. Virtually all studies conducted in recent decades have recognized the threatened ecological condition of springs ecosystems and the imperiled state of their biota. However, human demands for water often preclude their protection, and the complex, highly multi-disciplinary nature of springs research has retarded development of a comprehensive, conceptual approach to understanding springs as ecosystems.

We proposed a conceptual model of springs ecosystems (Stevens and Springer 2004). We developed the general model from a suite of dynamic ecosystem models, associated process-component mechanistic models, and a state-and-transition framework of human impacts on springs ecosystems. Such an effort is important to ground inventory, assessment, stewardship activities, and monitoring. Until it is more fully quantified and tested, the model will not provide much predictive capability, but it is needed to expose gaps in knowledge, uncertainty, and previously unrecognized interrelationships among springs ecosystems processes and components. When coupled with rigorous groundwater models, and with additional research, much new insight into springs ecology is likely to emerge from this model.

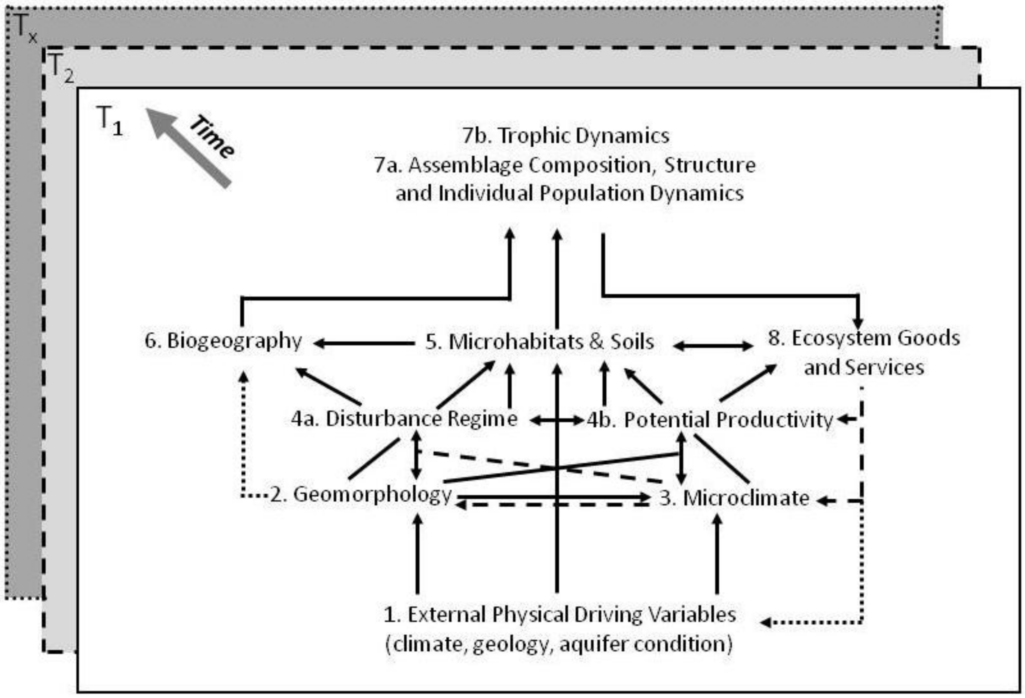


Fig. 1: A conceptual springs ecosystem model, showing the interactions among 8 submodels. T1-TX represents the springs ecosystem from time 1 through time x. Solid lines represent strong, direct effects and dotted lines indicate indirect or uncertain effects.

The many complex interactions between aspect and springs vegetation across elevation and among climate regions, provide a remarkably rich setting in which to better understand microclimate impacts on vegetation composition and structure. With enough springs inventory data, important baseline patterns may begin to be understood, particularly in relation to climate change.

Geohydrology of the Tucson Area

The geology and aquifers of the Tucson area have been actively researched because of concerns about declining groundwater levels. Mason and Bota (2006) summarize the stratigraphy and geology, precipitation, and groundwater pumping history of the Tucson basin (Table 1; Figs. 2-5).

Table 1: correlation of stratigraphic units and Tucson AMA model units to orogenic events (from Mason and Bota 2006).

Stratigraphic Units	Hydrologic Unit	Orogenic Events	Geologic Age	Geologic Period
Surficial Alluvium 0.01 – 1.3 m.y.a -------- unconformity ------	Upper Basin-Fill	General tectonic stability and development of through flowing drainage	Holocene	Quaternary
Fort Lowell Formation 1.3 – 2.2 m.y.a. -------- unconformity ------			Pleistocene 1.7 – 2.2 m.y.a.	
Upper Tinaja Beds 2.2 – 5.8 m.y.a. -------- unconformity (?)----		Second phase of Basin and Range faulting, 5.8 m.y.a and transition to tectonic stability by 2.2 m.y.a	Pliocene 4.9 – 5.3 m.y.a.	Tertiary
Middle Tinaja Beds 5.8 - 12 m.y.a. -------- unconformity (?)---	Lower Basin-Fill	Basin and Range faulting 12 – 2.2 m.y.a.	Miocene 23 – 26 m.y.a.	
Lower Tinaja Beds 12 – 24 m.y.a -------- unconformity ------		Transition from Mid-Tertiary Orogenic event to Basin and Range Disturbance, 24 – 12 m.y.a.		
Pantano Formation 24 – 35 m.y.a. -------- unconformity ------		Mid-Tertiary Orogenic Event 35 - 24 m.y.a.	Oligocene 34 –38 m.y.a.	
Pre-Oligocene Igneous, Sedimentary, and Metamorphic Rocks		Pre-Oligocene Geologic Event	Eocene 54 – 56 m.y.a.	
			Pre-Eocene	

After Anderson, 1987, Plate 1.
Million Years Ago – m.y.a.

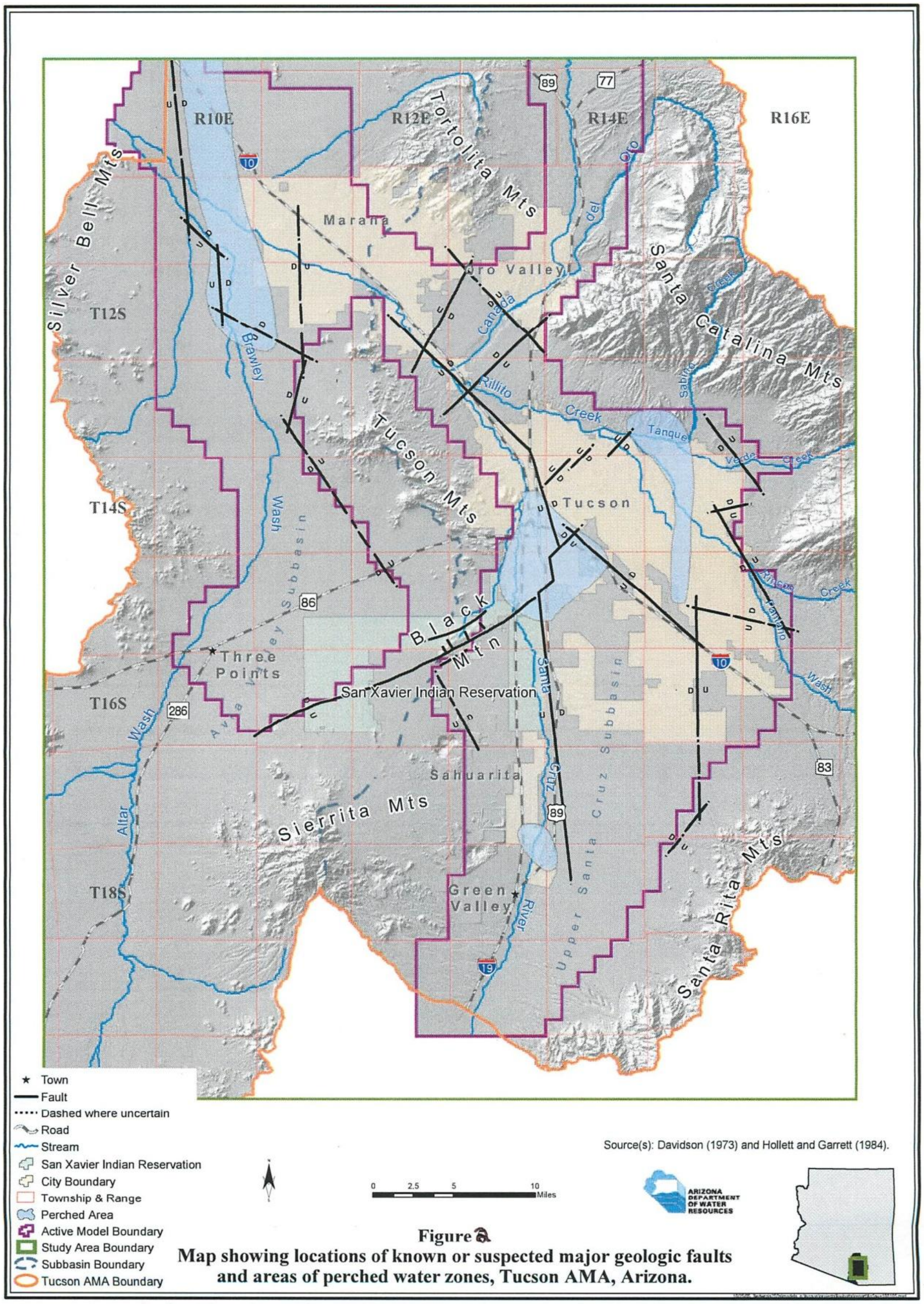


Fig. 2: Map showing locations of known or suspected major geologic faults and areas of perched water zones, Tucson AMA, Arizona (from Mason and Bota 2006).

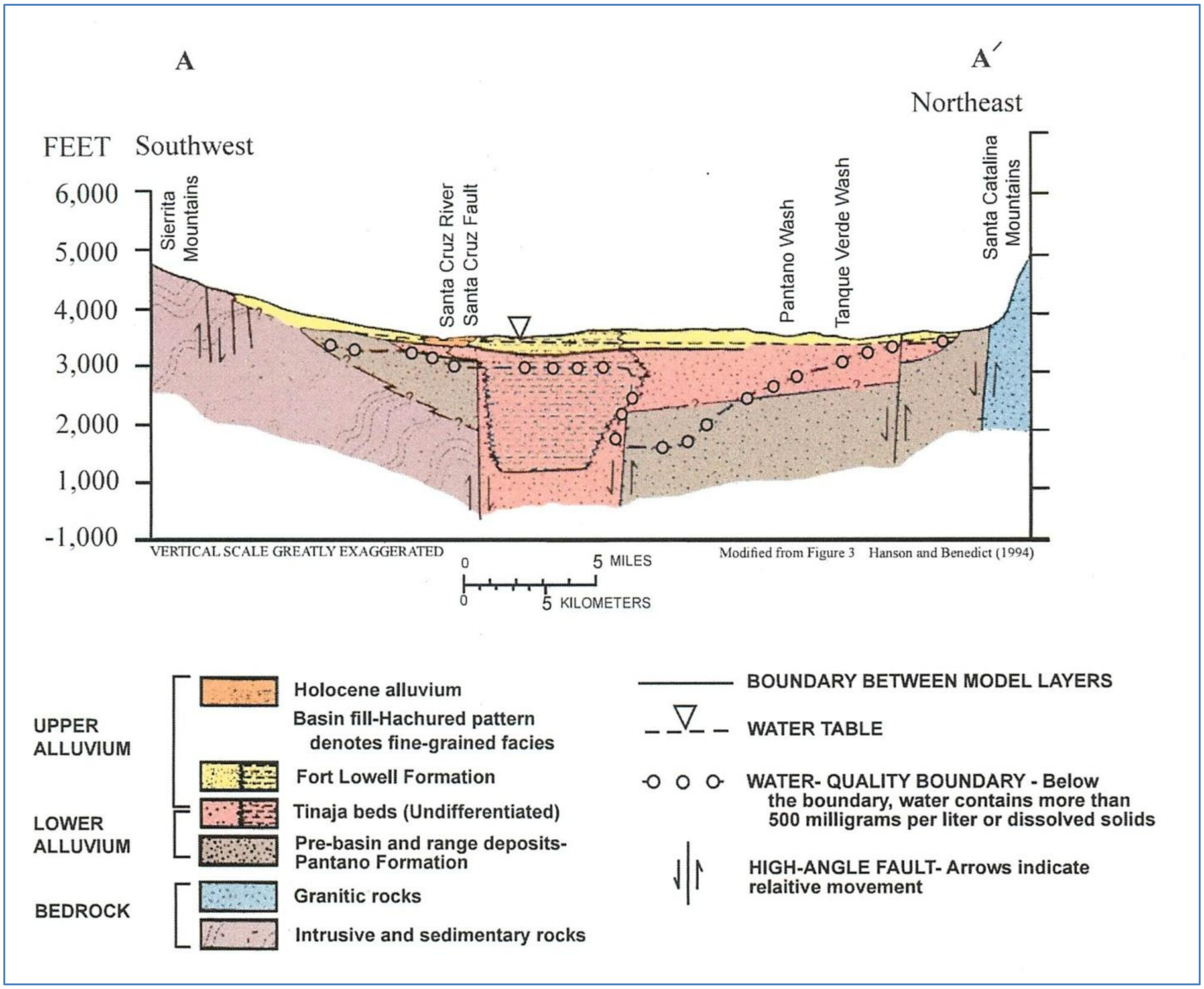
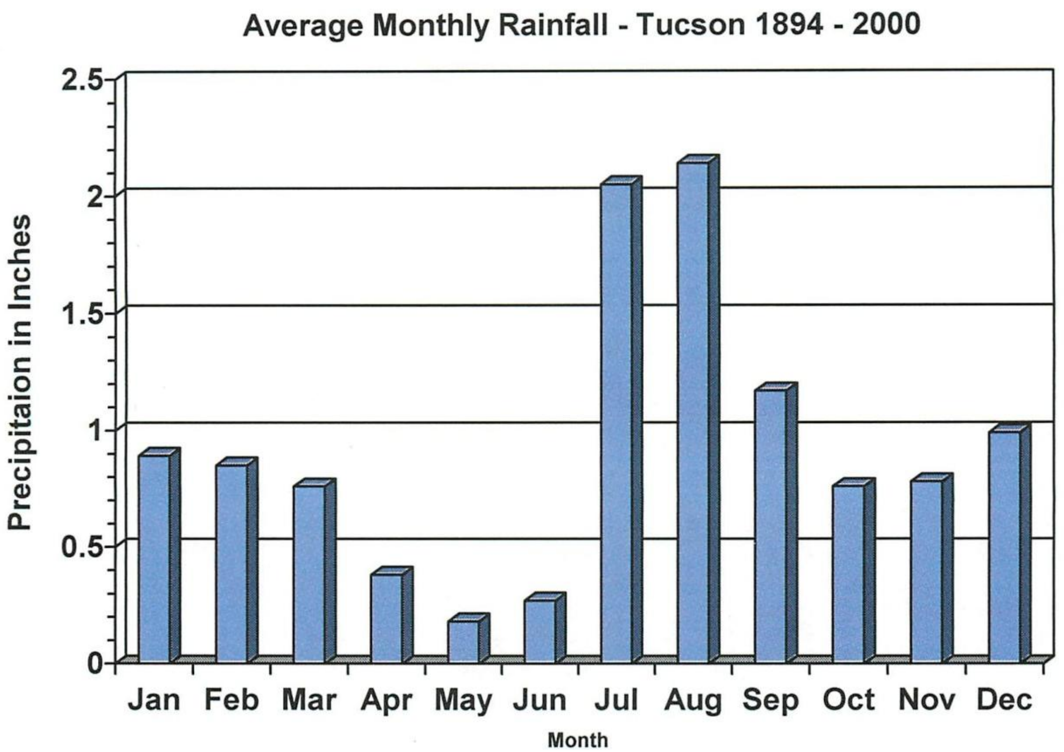


Fig. 3: Geologic cross-section of the Tucson basin, Tucson AMA, Arizona (from Mason and Bota 2006).



(Source: Hydrodata, 2001).

Fig. 4: Average monthly rainfall, 1896-2000, Tucson, Arizona (from Mason and Bota 2006).

CHAPTER 4: THREATS TO SPRINGS: HUMAN IMPACTS

Introduction

Human activities have greatly reduced the ecological integrity of many wetland, riparian and springs ecosystems through competing exploitative uses, including groundwater depletion, fuel wood harvest, recreation, livestock grazing, and wildlife management (Fig. 2). Overall estimates of springs and riparian habitat loss range from 40% to >93% in the arid southwestern United States, but assessment and understanding of human impacts at springs is only now emerging. Below we describe the array of human threats on springs and the ecological consequences of those impacts.

Altered Regional Groundwater Availability

Alteration of springs flows may arise from several potential anthropogenic impacts on aquifers. Anthropogenic climate change may reduce precipitation, infiltration and aquifer dynamics. Land-use change may alter the processes for recharge to an aquifer. For example, urbanization leads to an increase in impervious surface area over an aquifer, increasing the amount of surface runoff and decreasing the potential for recharge. Also, changes in land use by fire suppression or grazing can change the role of plant water use in a watershed and subsequently recharge to the aquifer. Reduction of the water-table elevation or well-drilling may allow inflow of lower-quality groundwater into an aquifer. In addition, pollution of percolating surface water or groundwater may reduce the quality of an aquifer's water. Extraction of groundwater from the aquifer may partially or wholly dewater individual springs or entire complexes of springs resulting in fragmentation of habitat, increasing isolation of springs ecosystems, and interruption of biogeographic processes at microsite-regional spatial scales in perpetuity. Groundwater augmentation may occur when aquifers are artificially recharged by urban run-off, when reservoirs increase water tables, or through climate changes that increase precipitation. Increased springs flow is often accompanied by a change in flow chemistry and pollutants.

A groundwater model was developed and tested by Mason and Bota (2006; Fig. 5). They reported,

> "The results of a Base Case projection simulation from 2000 to 2025 that maximized the utilization of renewable water supplies indicates that the Tucson AMA will not achieve its goal of reaching "Safe Yield" by 2025. However, the AMA-wide annual overdraft is projected to be between 14,000 and 20,000 acre-feet. The Avra Valley sub-basin will have a net increase in storage during the Base Case projection of about 453,000 acre-feet and water levels are projected to continue to recover due to extensive artificial recharge of renewable water and projected declines in agricultural pumpage. The Upper Santa Cruz sub-basin will experience a net loss of storage of 1,000,000 acre-feet; however, water levels are projected to rise in the City of Tucson's central wellfield area, T 14 S, R 14 E, for the period 2000 to 2020. The projected recovery is due to dramatically reduced withdrawals as pumpage is shifted to recovery of renewable supplies from

recharge projects. After 2020, the water level recovery in the central wellfield is projected to slow as increasing municipal demand is satisfied by increased pumpage. Water levels in the southern areas of the basin near the Santa Cruz River are projected to rise due to recharge projects. However, water levels are projected to decline by between 50 to 225 feet in the eastern and southeastern areas of the Tucson AMA where demand is expected to be satisfied by nonrenewable groundwater."

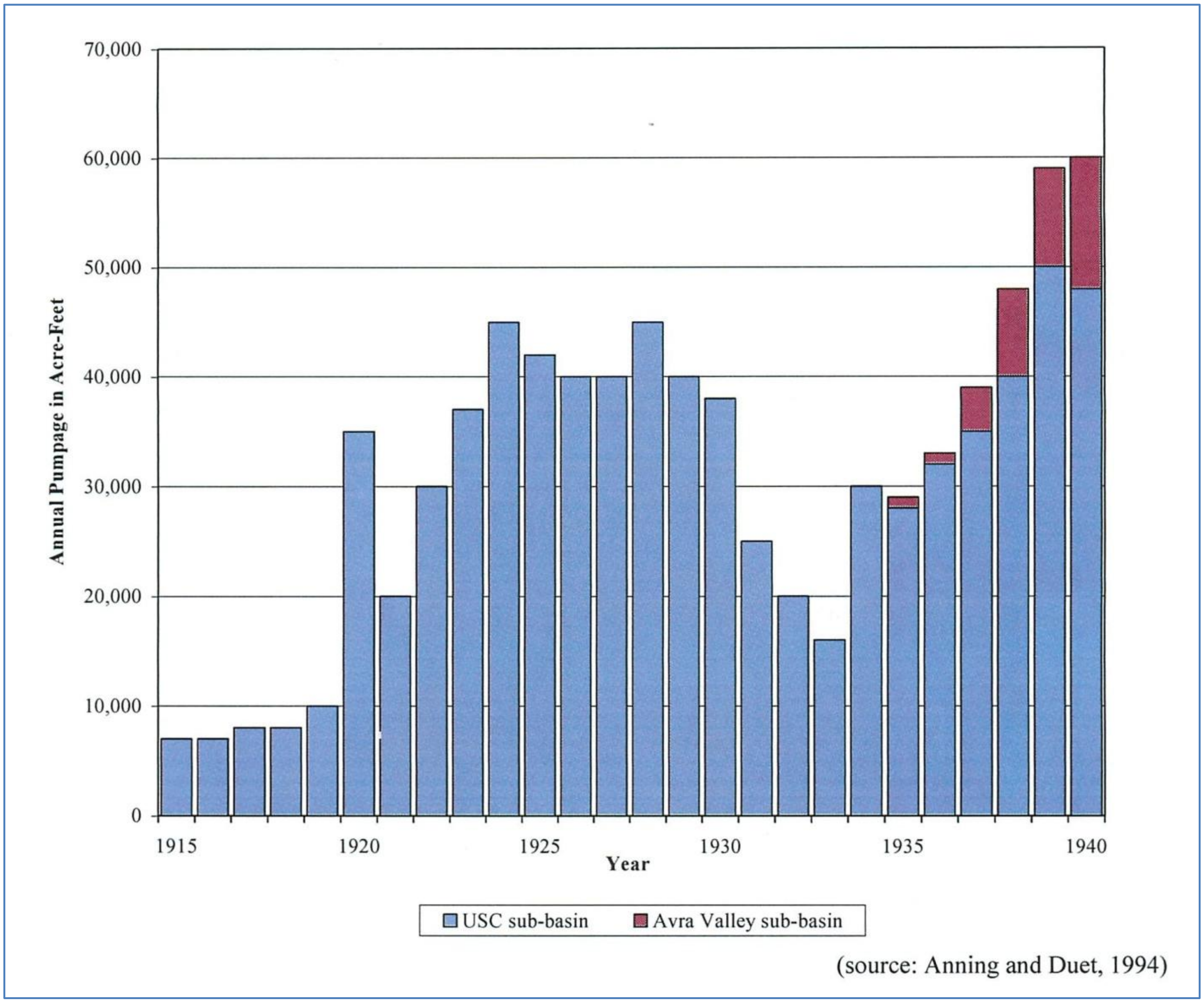


Fig. 5: Estimated pumpage in the Tucson area, 1915-1940 (from Mason and Bota 2006).

Pollution

Groundwater and surface water pollution strongly alters springs ecosystem integrity and is a common phenomenon in agricultural and urban areas. Agricultural groundwater pollution may shift ecosystem nutrient dynamics to entirely novel trajectories creating conditions to which few native species may be able to adapt. Non-point-source agricultural fertilizers have contaminated virtually all of the springs in Florida which emanate from shallow aquifers. Such increases in pollutant concentrations constitute a "push" form of disturbance on springs with effects lasting at least for more than the duration of the recharge cycle. Local contamination may also affect springs microhabitats by polluting surface waters. Such impacts are abundant at springs on the southern Colorado Plateau where springs sources are often fenced and concentrate ungulate use.

Local Flow Diversion

Springs have long been the target of human alteration to improve water supplies for culinary, livestock, and other uses. Following the lead of the Environmental Protection Agency, most states require that groundwater used for culinary purposes remain below-ground thereby avoiding exposure to surface contamination. The implications of this legal requirement have commonly meant that springs sources are dewatered before point of emergence or that facilities are constructed over the springs (spring boxes, spring houses, etc.), voiding their ecological functions. We have noted several forms of springs flow alteration including diversion from the pre-orifice (prior to the point of emergence) or post-orifice (after emergence) environment. Pre-source diversion is often achieved by: 1) sealing the springs orifice from bedrock (and sometimes sealing the surrounding bedrock fractures) and installing piping; or 2) excavating the springs source in colluviums or alluvium, installing a slotted pipe catchment system, back-filling the excavation, and piping the water. We also have noted that diverted springs flows on the Arizona Strip were sometimes piped more than 30 km from the source to the delivery point.

Post-orifice diversion is also common, particularly for livestock watering and development of ponds. Spring flows are commonly captured into open troughs or into covered tanks and then piped to troughs or ponds. These alterations may preserve some ecological function at the springs source, but often eliminate spring channel and cienega (wet meadow) functions.

Interruption of Disturbance Regimes

Humans commonly influence the frequency and type of disturbance, impacts that strongly affect springs ecological development. Surface-flow dominated springs are characterized by frequent flood events and considerable interannual flux in vegetation cover and diversity. For example, Grand Canyon Wildlands Council (2004) reported 10-70 percent variation in vegetation cover in one such spring that was monitored for three years. Moderate to high variability in the size and spatial arrangement of vegetation patches or aquatic invertebrate composition in such settings is a normal system attribute, and resilience to disturbance may be the only useable metric of ecosystem health other than wetted area or flow. Flow regulation may stabilize normally highly disturbed streamside springs ecosystems altering structural, functional, and trophic characteristics of springs. For example, LES reported that flood control of the Colorado River in Grand Canyon by Glen Canyon Dam resulted in a 40 percent increase in vegetation cover of Vaseys Paradise spring. This increase in habitat area likely allowed a large expansion of the endangered Kanab ambersnail population there. Flow regulation of ephemeral stream channels on the Colorado Plateau commonly occurs through the construction of cattle tanks, and such structures undoubtedly affect disturbance regimes of channel springs downstream; however, such effects have yet to be studied.

Ungulate Impacts

Foraging: The foraging of large ungulates, such as cattle, horses, sheep, elk, deer, can devastate springs ecosystems by removing vegetation cover, altering plant and invertebrate assemblages, increasing erosion, and contaminating surface water (Grand Canyon Wildlands Council 2002). These impacts may be further intensified if the source is fenced to control ungulate movement.

Ungulate Trampling: Livestock grazing continues to exert pervasive adverse influences on springs and other riparian habitats because riparian zones provide water, shade, and succulent vegetation. Although livestock grazing impacts on springs have received relatively little attention, much attention has been devoted to understanding, assessing, and improving management of grazed wetland and riparian habitats.

Exotic Plant and Animal Invasions

Widespread introduction of non-native species may similarly greatly compromise ecological functioning at springs. The susceptibility of springs ecosystems to invasion by alien (non-native) species is a complex function of interactions among abiotic and biotic factors, introduction history, and invading species autecology. Non-native species are abundant at springs across the southern Colorado Plateau (Grand Canyon Wildlands Council 2002; Stevens and Ayers 2002).We found that non-native species in northern Arizona and southern Utah include at least 247 plant, 7 invertebrate, 39 fish, 1 amphibian, 2 reptile, 8 bird, and 13 mammal species. Alien plant and animal species were abundantly but unevenly distributed across seven groups of ecosystems in the Grand Canyon region. A total of 155 alien vascular plant species (10.4% of the total flora) and 33 alien vertebrates (7.3% of the total vertebrate fauna) were detected there. In contrast to Elton's prediction that invasibility should be negatively correlated with diversity, recent studies report spatial scale-dependent and fertility-related positive correlations among alien and native plant species diversity. The Colorado River corridor, other riparian areas including springs, and areas with high densities of roads and livestock trails had the highest densities of alien species. Alien species richness and density vary among ecosystems there in relation to relative productivity and relative disturbance intensity, and alien diversity was positively correlated with native biodiversity. Therefore, it appears that highly diverse ecosystems, such as springs, are most prone to alien invasions and attendant changes in composition, trophic structure, and function. These studies provide welcomed insight into habitat invasibility and alien population eruptions which are among the most significant, long-lasting and complex anthropogenic impacts on the world's ecosystems.

Although the life history strategies of eruptive alien species have been studied, many efforts to predict which introduced species will erupt and where eruptions compromise ecosystem integrity have met with limited success. In part this is because alien population eruption often occurs irregularly across spatial scales and among habitats and ecosystems within a biome (Horvitz et al. 1998). Also, alien eruption may be greatly delayed after initial colonization: Kowarik (1995) reported that on average 147 yr elapsed between introduction and eruption of alien populations around Brandenburg, Germany.

Fire Effects

The impacts of anthropogenic fire on springs have been little studied. Graham (2008) presents data on the slow recovery responses of a hanging garden to visitor-caused fire in southern Utah. The Grand Canyon Wildlands Council (2002) presented limited data indicating the potentially more rapid recovery of a spring than adjacent coniferous forest in northern Arizona. However, recovery of a burned hanging garden spring in one study in southern Utah was remarkably slow. Evidence from the White Mountain Apache Tribe indicates that springs wetland vegetation at White and other springs may recover relatively quickly after forest fires, but that springs were collaterally damaged by increased sheet flow erosion and channel-cutting (Burnette et al. 2003). Research in progress in Hart Prairie, northern Arizona by Springer indicates that reintroduction of fire to upland forests above wet meadows has the potential to increase water yield to the wet meadows.

Visitor Impacts

Recreational use impacts at springs have long been a concern at springs in some National Park Service units with management attention focused at Vaseys Paradise and other recreationally heavily used springs in Grand Canyon and at hanging gardens in Zion National Park. In most cases, creation and maintenance of discrete trails greatly reduces visitor impacts at springs; however, focused visitation is likely to affect larger wildlife populations and reduce springs-uplands trophic linkage.

Mining Impacts

The impacts of mines on springs may involve ground and surface water abstraction, diversion, regulation, or pollution, as well as construction and processing impacts and disturbances. Mine-related pollution and dewatering operations can significantly alter groundwater discharge to springs. Also, for submarine springs, mining of geothermal mineral deposits can do much damage to spring source geomorphology and biota.

Traditional Use and Science Impacts

Trampling may occur during traditional uses and research. Such disturbances may or may not affect springs ecosystem processes depending on the size and type of the spring, its susceptibility to disturbance, and the intensity of activity. Overharvesting may be an issue in ethnobiology, and handling of rare fish or other vertebrate species may reduce population viability. For example, concern exists that tag-marking and electro-shocking of a great percentage of the total adult humpback chub may be implicated in the decline of this endangered fish species in Grand Canyon.

Management Impacts

Management actions to protect springs often simply involve site closure, prohibiting visitation, or creation of discrete trails to allow visitors to reach the springs but limit their impacts. If done without inventory and assessment information, such actions may actually damage, rather than help recover, the springs ecosystem (Kodrick-brown and brown 2007). For example, fencing livestock out of a spring source may allow excess vegetation to develop eliminating surface water and threatening aquatic species persistence. Maintaining a sufficient disturbance regime to create some open water and space may be an important management decision. Creation of a surfaced trail to facilitate visitation (e.g., as occurs at some hanging garden springs) may eliminate leaf litter and prohibit movement of land snails and other invertebrate species. However, erosion can become a serious influence on springs geomorphic integrity if management fails to construct and maintain a trail to a regularly visited springs.

Restoration actions also may affect springs ecosystems, particularly if restoration goals fail to consider the range of natural variability of discharge, habitat area, and natural environmental impacts, such as fire, flooding, or rockfall.

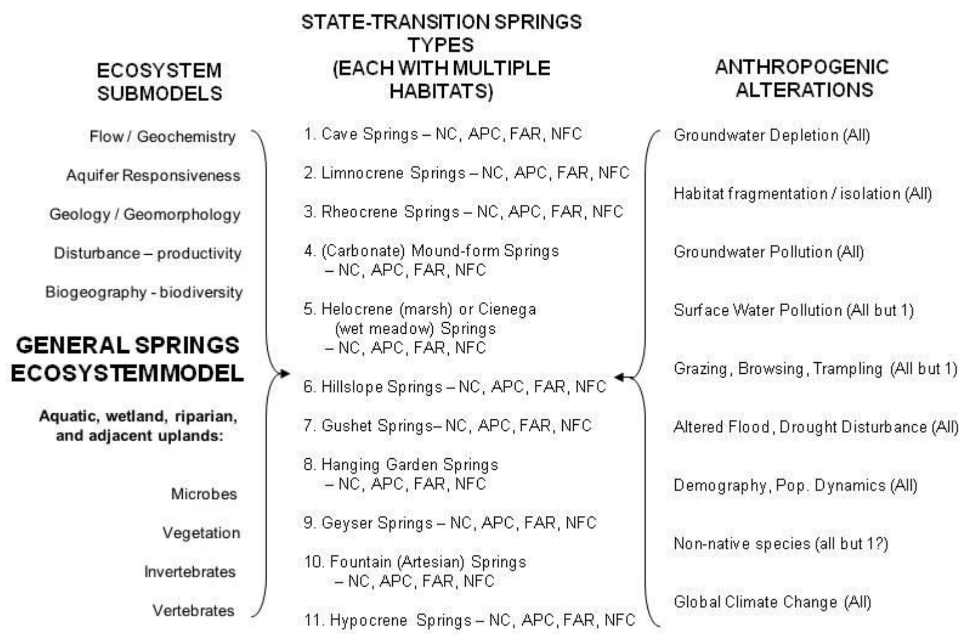


Fig. 2: Springs state-transition submodels, springs types, and anthropogenic alterations. Ecological functioning impacts: NC – natural condition; APC – acceptable functioning condition in relation to management plan; FAR – ecological functioning at risk, impaired; NF – non-functional.

CHAPTER 5: RESTORATION AND REHABILITATION OF SPRINGS

Much hyperbole touts the notion of sustainable ecosystem management – forests that can be perpetually farmed for trees, ocean fisheries that can be forever exploited despite enormous impacts of by-catch, and rangelands that can forever withstand intensive livestock grazing. Most of the hype over sustainability has arisen after it's too late – the ecosystem damage has been done, but the demand for the ecosystem goods is so great that we are forced to re-conceptualize our justification for the ecological overdraft.

Pakoon Springs in 2007 (above) and 2011 (below, with rehabilitation effort well underway.

Springs are heavily used by humans for domestic and livestock water, and other natural resources. However, unlike many ecosystems, if the aquifer is relatively intact, springs can be rescued and rehabilitated very effectively.

A case in point is the U.S. Bureau of Land Management's collaboration with the Grand Canyon Wildlands Council in the rehabilitation of Pakoon Springs in northwestern Arizona. This former ostrich and cattle ranch is one of the largest springs on the Arizona Strip, and was sold to the BLM in 2005. After removing an alligator and more than 100 tons of scrap metal, ostrich stalls, and numerous rundown ranch buildings, the restoration team reconfigured the landscape and replanted native wetland and riparian plants and trees. The first year after geomorphic rehabilitation, native wetland vegetation quickly began to regrow across the site and native insects, amphibians, reptiles, birds, and mammals recolonized the former ranch site. Today, the recovery of native species has created one of the finest patches of wetland-riparian springs habitat on the Arizona Strip.

Many other examples of successful springs restoration projects across the United States are documented by Davis et al. (2011), and demonstrate that springs are extraordinarily resilient, provided groundwater flow is maintained. Because this is the case for a great many springs, there is much hope for improved springs management for both natural ecological function while still providing goods and services to springs stewards.

CHAPTER 6: SPRINGS INVENTORY AND MONITORING

Overview

Improving springs stewardship requires assessment, planning, implementation, and monitoring, all of which are best when based on rigorous, scientific inventory. We have developed springs inventory and monitoring protocols that rigorously but efficiently to 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. Systematic inventory is important for assessment, management planning and action, and monitoring. Interdisciplinary inventory data also are needed for improving understanding of springs ecosystem ecology, distribution, status, and restoration.

Here we introduce and describe efficient, effective inventory and monitoring protocols for springs. These techniques are derived from a review of the scientific literature, and a decade of field experience across North America, inventorying many different kinds of springs subjected to numerous uses, from pristine springs in national parks, to springs fenced to focus livestock grazing, springs used for domestic water supplies, and springs used for intensive recreation. This Springs Inventory Protocol (SIP) is based on the springs ecosystem conceptual model of Stevens and Springer (2004), is directly related to the Springs Inventory Database, and informs our Springs Ecosystem Assessment Protocol (SEAP) to provide guidance for springs stewards.

The most recent version of the Springs Inventory Protocols (SIP) is available online at: http://springstewardship.org. A description of the Springs Inventory Database is available online at: http://springstewardship.org/database.html.

Given the challenges associated with mapping springs and understanding springs distribution at various scales, we normally recommend three levels of inventory to springs stewards. These approaches are described in more detail below. However, the data collection described in this manual represents a hybrid approach between Levels 1 and level 2, an approach adapted to assist the Sky Islands Alliance in its evaluation of springs ecosystem health in southeastern Arizona.

Level 1 Inventory: Level 1 inventory involves georeferencing individual springs, photographing the site, determining the sphere of discharge (Table 1), evaluating flow magnitude and what equipment is needed to measure flow, and recording anecdotal observations about ecosystem resources and ecological conditions. Level 1 inventories are designed as brief site visits usually conducted by citizen scientists or non-expert technicians to promptly and efficiently document the location and general characteristics of springs. Data are recorded on the first page of the SIP field sheets. Additional details of Level 1 data collection are described in the springstewardship.org website.

Level 2 Inventory: Level 2 springs inventory includes an array of measured, observed, or otherwise documented variables related to site and survey description, biota, flow, and the sociocultural-economic conditions of the springs at the time of the survey. These inventories are conducted by a team of 3-4 experts, often with 1-2 assistants on a 1 to several hour site visi; however, 1-2 additional days of office time per site may be needed for compilation of background information, laboratory analyses, completion of data management, and reporting for a study site. Expertise within the inventory team includes geography, information management, hydrogeology, botany, ecology, and cultural resources. The team gathers information on flow, water quality, geomorphology, sphere of discharge (Table 1), habitat characteristics, flora and fauna, human influences, and the administrative context of stewardship.

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 (2008), and are based on the springs ecosystem conceptual model of Stevens and Springer (2004) and Stevens (2008). These variables considered 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.

Monitoring protocols are selectively derived from Level 2 inventory approaches, and are applied in Level 3 efforts (below). Details of Level 2 data collection are described in the clarifying criteria at the end of the field data sheets, and further data collection details and entry of data from the field sheets into the SSI springs database are described at the springstewardship.org website.

With appropriate background information, a Level 2 springs sampling visit is sufficient for assessment of ecosystem integrity using the Springs Ecosystem Assessment Protocol approach described below. Level 2 inventory protocols and information management protocols also can be used as a baseline for longer-term Level 3 site management and restoration efforts. The Level 2 approach is designed as a rapid assessment of a springs ecosystem. We regard activities such as wetland delineation, soil profile analyses, paleontological and historical use investigations, and other in-depth scientific and management activities as Level 3 activities, and to time- and labor-expensive for Level 2 inventory.

Level 3 Inventory: Level 3 inventory of springs involves longer-term monitoring, often for planning and implementing rehabilitation, conducting other management actions, or research. Level 3 inventory is defined loosely to accommodate various and often detailed inquiries into springs ecological change over time or responses to treatments through multiple bouts of sampling and site visits.

Table 1: Spheres of discharge and emergence characteristics of various types of springs.

Discharge Sphere	Emergence Characteristics
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 in a well-defined stream channel
Mound-form springs	Emerge from (usually carbonate) precipitate mounds
Heleocrene springs	Emerge usually in a diffuse fashion in marshy, wet meadow, fen, or cienega settings.
Hillslope springs	Emerge from non-vertical hillslopes at 30-60^{o} slope, usually with indistinct or multiple 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	Usually geothermal springs that emerge explosively and usually erratically
Fountain springs	Cool-water artesian springs forced above the land surface by stratigraphic head-driven pressure.
Exposure springs	Settings in which groundwater is exposed at the surface but does not flow
Hypocrene springs	Springs in which groundwater approaches but does not quite reach the surface.

Safety Issues

Staff Safety: Protection of staff who are searching for springs in remote landscapes requires attention to personal safety and the oversight of the crew leader. Injuries, accidents, confrontations with unreceptive individuals, as well as inclement weather all pose potentially serious threats to springs assessors. Safety threats can be reduced by having a clear plan of action, considering contingencies, wearing proper clothing, using high quality radios when in remote settings, carrying appropriate first responder equipment, carrying sufficient food and water, and knowing one's own and one's companions limits. The crew leader should be specifically trained in wilderness first aid, and should carry either a cell phone (if cell phone service covers the study area) or a satellite phone.

Preventing Chytrid Fungus Infection in Springs: The following passage is quoted from the U.S. Forest Service "Protect Your Waters Program" (2012).

> "The greatest concern for amphibian populations at this point involves the chytrid fungus. A large amount of research and resources has been dedicated to understanding why and how this fungus is responsible for the decline of the wild boreal toad. Until we can easily detect, treat, and/or prevent this pathogen from causing irreparable mortality to the wild populations, we must prepare for the worst case scenario. This fungus was observed in a wide range of the amphibian population, with die-offs in Panama and Australia. The fungus has also been identified in some amphibian populations in Arizona and has caused the death of many zoo Amphibians in the United States. Scientists don't know how this fungus is transmitted from one area to another, let alone why the fungus is affecting amphibian populations around the world. Whether the chytrid fungus is responsible for the frog or toad mortality or the declines of frogs and toads in many western states is still unknown. Because fungal infections are considered secondary infections in other vertebrates, USGS is completing further tests for viruses, parasites and bacteria to rule out other factors that could predispose the animals' susceptibility to the fungus. Sick and dying toads in the Colorado population were first discovered in May of 1999. Live toads show few clinical signs of the disease, but some may appear weak, lethargic and

reluctant to flee at the approach of humans. Upon being examined microscopically many of the dead toads showed a myriad of minute chytrid fungi in the skin of the abdomen and toes. Where did the chytrid fungus come from? We know that there are about 80 species of chytrid fungus world wide, which feed on algae, plant material, keratin, etc. But how did the amphibian chytrid come to be toxic to the boreal toad? Did it mutate from another chytrid? Was it altered by environmental conditions to become toxic? How does chytrid kill amphibians? Does it suffocate them? Does it poison them? Does it alone kill the toad or does it cause something else to happen which kills the toad? Why does chytrid kill all the toads in a specific area and not another? Has chytrid fungus always been around but not active all the time, or has it come from somewhere else and is being spread by something such as another host, weather patterns, people, etc.? Or is this a new disease which is being spread? Much research needs to be done needless to say. "

Disinfecting your Gear

Heat gear to 140^{o} F (60^{o} C) for 5 minutes, or 117^{o} F (47^{o} C) for 30 minutes.
Dry the gear for 48 hrs at less than 70% relative humidity.
Chlorine bleach (4% solution) for 3 minutes.

The FS web address for more information is:
http://66.102.7.104/search?q=cache:HZxSluZRxTYJ:www.azadoc
ents.org/boreal_toad.pdf+chytrid+fungus+prevention&hl=en

Springs Inventory Equipment List

Day pack or backpack
Background data
Map to site
GPS unit – set to NAD83 Horizontal Datum
- spare GPS batteries

Field data sheets
SEAP scoring criteria
Pencils
Clipboards
Graph paper for sketchmap
30-100 meter measuring tape or range finder
Solar Pathfinder and templates for latitude
Sighting compass or Brunton compass
Clinometer
Trowel or shovel
Binoculars
Hand lens
Water quality kit (EC or SC, pH, temperature, dissolved oxygen)
Handheld thermometer (backup)
Flow measurement
- capture pipes
- calibrated volumetric containers
- weir plate
- plastic sheet
- stopwatch

Natural history field guides
Camera
- memory cards
- spare battery

Personal items (hat, bandana, food, water, sunscreen, warm clothing)
Cell or satellite telephone
First aid kit

CHAPTER 7: SEAP—A SPRINGS ECOSYSTEM ASSESSMENT PROTOCOL

A comprehensive, broadly applicable assessment protocol is needed to: 1) evaluate and compare the ecological health of springs ecosystems, 2) detect change and trends over time, and 3) develop management priorities at local, regional, national, and global scales. We developed a springs ecosystem assessment protocol (SEAP) to evaluate the ecological status or condition, and the risks and restoration potential within and among springs. The SEAP is based on a conceptual ecosystem model developed by Stevens and Springer (2004), and it incorporates information from on-site inventory, literature review, and interviews with the resource manager(s), as well as recent advances in springs classification (Springer and Stevens 2008; Springer et al. 2008). This assessment process ranks the condition (or value) of each subcategory, and the risk to that subcategory resource variable. Risk is interpreted as the potential threat or the "condition inertia" (probability of remaining unchanged, the inverse restoration potential) of that variable. The SEAP includes evaluation of six overall categories of variables, including the supporting aquifer, site geomorphology, the habitat and microhabitat array, and the site biota, all in relation to human uses and influences, and the administrative context under which the spring is managed. Each category is scored on the basis of 5-8 subcategory variables, which are ranked on a 0-6 scoring scale by the inventory team (categories 1-5, aquifer integrity to human influences) and through a discussion with the land or resource manager (category 6). Category scores are averaged from subcategory scores, and the overall ecological health score is evaluated in relation to human influences, and compared with the stewardship plan for the site.

The SEAP has the flexibility to be developed from several levels of information and time/funding availability, including: a very rapid, in-office assessment developed by a manager with good understanding of a site; the results of a brief (10-20 minute) Level 1 rapid field examination of the site; or a comprehensive Level 2 inventory conducted by a team of 3-4 experts during a several-hour site visit. The SEAP's quantitative approach also allows it to be used as a monitoring tool, permitting comparison of ecological condition over time, or following management actions. As an example, we conducted a Level 2 inventory of Montezuma Well, a large limnocrene (pool-forming spring) in Montezuma Castle National Monument in central Arizona. The SEAP produced from that inventory showed that the Well was in fairly good ecological condition but is threatened by regional groundwater pumping and intensive recreational impacts.

We tested the SEAP on springs in several regional landscapes (southern Alberta, southern Nevada, northern Arizona, and elsewhere), managed by various federal, provincial, tribal, and local stewards. Our studies to date show the SEAP to be broadly and multi-culturally applicable, efficient, comprehensive, and specifically informative for virtually all spring ecosystems. Analysis of large suites of springs in those studies reveals strong responses of springs types and habitats to anthropogenic stressors, particularly groundwater depletion, flow diversion, geomorphic alteration, livestock grazing, and non-native species introductions. We used the results of the SEAP to advise federal and tribal managers on prioritized stewardship and restoration options, advice has been used to undertake springs restoration projects in Ash Meadows, Nevada (Otis Bay 2006) and on the Arizona Strip (Grand Canyon Wildlands Council

2002, 2010). We expect and welcome future improvement of the SEAP approach as additional data are compiled and further analyses are undertaken. We invite interested individuals and agencies to consider using both the SEAP and the springs inventory protocol on which it is based to prioritize understanding and improve stewardship of springs ecosystems in all landscapes.

Completion of a SEAP form for each site visited is one of the goals for the field-based component of the Sky Islands Alliance springs assessment project. Therefore, we recommend that assessors carefully study the SEAP questions and scoring criteria (provided at the back of the SEAP field form). Furthermore, we recommend that the site visit team collectively decide site scoring information.

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Page ______ of _________ OBS____________

General

[1] Spring Name___________________________ Country____ State_______ County______________________

Land Unit_____________ [2] Land Unit Detail_____________ Quad_________________ HUC_______________

Access Directions

Georef

Georef Source_____________ Device__________________________ Datum_______________ UTMZone________

UTM E__________________ UTM N__________________ Lat____________________Long____________________

Elev______ EPE______ feet or meters? Declination _____ Georef Comments____________________________

Survey

Date__________________ Begin Time_______________ End Time________________

Surveyor's Names____ Project____________________

Microhabitats

Code/Description	Area (m²)	[3] Surf Type	[4] Sub-Type	[5] Slope Var	Aspect noteT or M	Slope Deg.	[6] Soil moisture	Water dpth(cm)	Water %	[7] Substrate % 1	2	3	4	5	6	7	Org	Precip %	Litter %	Wood %	Litter (cm)
A																					
B																					
C																					
D																					
E																					
F																					
G																					

[13] Discharge Sphere_______________________________ Site Condition_______________________________

Site Description_______________________________

Images

Camera Used_______________________________

Sketch Map Location_______________________________

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 _________________

Spring Name____________________________ Page _______ of __________ OBS_____________

Water Quality

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?	DuplicateTaken?	Container	Filtered (Y/N)	Treatment	
Anions						
Cations						
Nutrients						
^{2}H 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)	☐		Isolation			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
1 - Dry
2 - Dry-Moist
3 - Moist-Dry
4 - Wet-Dry
5 - Moist
6 - Saturated-Dry
7 - Wet
8 - Saturated-Moist
9 - Wet-Saturated
10 - Saturated
11 - Inundated

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

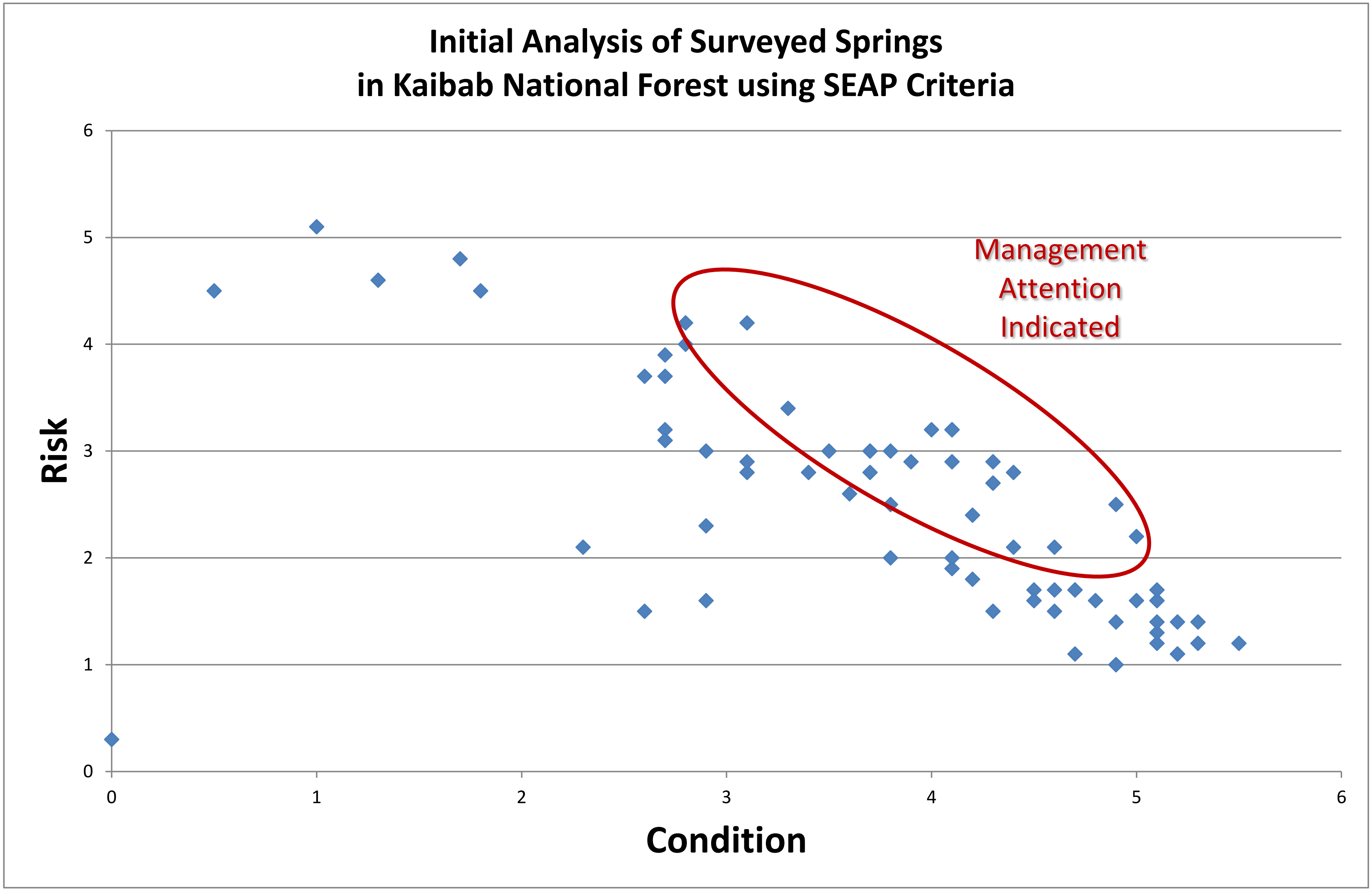
12 Channel Dynamics
Mixed runoff/spring dominated
Runoff dominated
Spring dominated
Subaqueous

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
NV Nonvascular (moss, etc)
BC Basal Cover



Initial Analysis of Surveyed Springs
in Kaibab National Forest using SEAP Criteria
Risk
Condition
Management
Attention
Indicated
0
1
2
3
4
5
6

Site______________________ Date__________ Info Source______________

Springs Ecosystem Assessment Protocol Scoring Criteria

Aquifer and Water Quality

AFWQ0 Spring Dewatered (Y/N)

AFWQ1 Aquifer functionality

0 Aquifer depleted
1 Aquifer nearly depleted
2 Aquifer in significant decline
3 Aquifer declining slightly but detectably
4 Low to moderate aquifer withdrawal
5 Aquifer not or only very slightly pumped
6 Aquifer pristine; good potential reference site
9 Unable to assess aquifer functionality

AFWQ2 Spring discharge

0 No flow
1 Less than .1 liters per second
2 Between .1 and 1 liters per second
3 Between 1 and 10 liters per second
4 Between 10 and 100 liters per second
5 Between 100 and 1000 liters per second
6 Over 1000 liters per second
9 Unable to assess flow

AFWQ3 Flow naturalness

0 Springs dewatered
1 Springs mostly dewatered
2 Springs flow strongly reduced
3 Springs flow slightly, but distinctively, reduced
4 Springs flow only slightly reduced
5 Springs flow apparently natural
6 Springs pristine; good potential reference site
9 Unable to assess flow naturalness

AFWQ4Flow persistance

0 No springs flow
1 Flow ephemeral, less than 50% of time
2 Flow rarely ephemeral
3 Flow recently persistent
4 Flow apparent during Holocene
5 Flow continuous since late Pleistocene
6 Flow since mid-Pleistocene or earlier
9 Unable to assess flow persistance

AFWQ5Water quality

0 No water
1 Water quality less than 10% of natural condition
2 Water quality 10 to 30% of natural condition
3 Water quality 30 to 60% of natural condition
4 Water quality 60 to 90% of natural condition
5 Water quality 90 to 99% of natural condition
6 Water quality fully natural
9 Unable to assess water quality

AFWQ6 Algal and periphyton cover

0 Algal or periphyton cover wholly unnatural
1 Natural cover of algae or periphyton very poor
2 Natural cover of algae or periphyton poor
3 Natural cover of algae or periphyton moderate
4 Natural cover of algae or periphyton good
5 Natural cover of algae or periphyton very good
6 Cover of algae or periphyton wholly natural
9 Unable to assess algal and periphyton cover

Geomorphology

GEO1 Geomorphic functionality

0 Site obliterated unnaturally
1 <25% original natural microhabit types remain
2 25-50% of natural microhabitat types remain
3 50-75% of natural microhabitat types remain
4 75-90% of natural microhabitat types remain
5 90-98% of natural microhabitat types remain
6 Natural microhabitat types pristine
9 Unable to geomorphic functionality

GEO2 Runout channel geometry

0 Original runout channel unnaturally obliterated
1 Channel virtually obliterated, trenched, or otherwise manipulated
2 Channel strongly altered, with only scant evidence of original course
3 Channel highly altered but with some functionality
4 Channel slightly altered, mostly functional
5 Channel functioning apparently naturally
6 Channel pristine
9 Unable to assess channel geometry

GEO3 Soil integrity

0 Natural soils eliminated
1 Virtually all natural soils eliminated
2 Soils thin or eliminated on most of site but a detectable amount remaining
3 Soils patchy and compromised, with degraded functionality
4 Soils large intact, and only slightly compromised
5 Soils apparently natural, with very minor reduction in functionality
6 Soils fully natural
9 Unable to assess soil integrity

GEO4 Geomorphic diversity

0 None; a completely unnatural condition
1 Very low geomorphic diversity
2 Low geomorphic diversity
3 Moderate geomorphic diversity
4 Good geomorphic diversity
5 Very good geomorphic diversity
6 Pristine; fully natural geomorphic diversity
9 Unable to assess geomorphic diversity

GEO5 Natural physical disturbance

0 Natural disturbance regime obliterated
1 Natural disturbance regime virtually eliminated
2 Highly altered natural disturbance regime
3 Moderately altered natural disturbance regime
4 Little altered natural disturbance regime
5 Nearly natural disturbance regime
6 Natural disturbance regime virtually pristine
9 Unable to assess natural disturbance regime

Site______________________________ Date_____________

Habitat

HAB1 Natural spatial configuration

0 <10 m from the nearest springs ecosystem
1 10-50 m from the nearest springs ecosystem
2 50-100 m from the nearest springs ecosystem
3 100-500 m from the nearest springs ecosystem
4 500-1000 m from the nearest springs ecosystem
5 1-10 km from the nearest springs ecosystem
6 >10 km from the nearest springs ecosystem
9 Unknown distance to nearest springs ecosystem

HAB2 Habitat patch size

0 No springs habitat area
1 < 10 sq m habitat area
2 10 - 100 sq m habitat area
3 100-1000 sq m habitat area
4 .1 - 1 hectare habitat area
5 1 - 10 hectare habitat area
6 >10 hectare habitat area
9 Unable to assess habitat area

HAB3 Microhabitat quality

0 No microhabitats exist or remain
1 Very low microhabitat quality
2 Low microhabitat quality
3 Moderate microhabitat quality
4 Good microhabitat quality with some indication of impairment
5 Very good microhabitat quality, but past impairment suspected
6 Pristine microhabitat quality
9 Unable to assess microhabitat impairment

HAB4 Native plant ecological role

0 No native plant species present
1 Native species cover and biomass <25% of natural condition
2 Native species cover and biomass 25-50% of natural condition
3 Native species cover and biomass 50-75% of natural condition
4 Native species cover and biomass 75-90% of natural condition
5 Native species cover and biomass 90-98% of natural condition
6 Native species cover and biomass virtually pristine
9 Unable to assess native plant species' ecological role

HAB5 Trophic dynamics

0 No trophic dynamics occurring
1 Trophic dynamics and ecological efficiency scarcely extant (<25%)
2 Trophic dynamics and ecological efficiency poor (25-50%)
3 Trophic dynamics and ecological efficiency moderate (50-75%)
4 Trophic dynamics and ecological efficiency fair (75-90%)
5 Trophic dynamics and ecological efficiency good (90-98%)
6 Trophic dynamics and ecological efficiency pristine (>98%)
9 Unable to assess trophic dynamics and ecological efficiency

Biology

BIO1a Native plant richness/diversity

0 No native plant species remaining
1 <25% of expected species remaining
2 25-50% of expected species remaining
3 50-75% of expected species remaining
4 75-90% of expected species remaining
5 90-98% of expected species remaining
6 >98% of expected species remaining
9 Unable to assess native aquatic & wetland vascular plant richness-diversity

BIO1b Native faunal diversity

0 No native aquatic invertebrates
1 <25% of expected species remaining
2 25-50% of expected species remaining
3 50-75% of expected species remaining
4 75-90% of expected species remaining
5 90-98% of expected species remaining
6 >98% of expected species remaining
9 Unable to assess native aquatic faunal diversity

BIO2a Sensitive plant richness

0 No sensitive or listed plant species remain
1 <25% of expected species remaining
2 25-50% of expected species remaining
3 50-75% of expected species remaining
4 75-90% of expected species remaining
5 90-98% of expected species remaining
6 >98% of expected species remaining
9 Unable to assess native aquatic & wetland sensitive vascular plant species

BIO2b Sensitive faunal richness

0 No sensitive or listed faunal species remain
1 <25% of expected species remaining
2 25-50% of expected species remaining
3 50-75% of expected species remaining
4 75-90% of expected species remaining
5 90-98% of expected species remaining
6 >98 of expected species remaining
9 Unable to assess native aquatic & wetland sensitive faunal species

BIO3a Nonnative plant rarity

0 >75% of plant species are non-native
1 50-75% of plant species are non-native
2 25-50% of plant species are non-native
3 10-25% of plant species are non-native
4 5-10% of plant species are non-native
5 2-5% of plant species are non-native
6 <2% of plant species are non-native
9 Unable to assess nonnative plant species rarity

BIO3b Nonnative faunal rarity

0 >75% of faunal species are non-native
1 50-75% of faunal species are non-native
2 25-50% of faunal species are non-native

3 10-25% of faunal species are non-native
4 5-10% of faunal species are non-native
5 2-5% of the faunal species are non-native
6 <2% of faunal species are non-native
9 Unable to assess nonnative aquatic & wetland faunal species rarity

BIO4a Native plant demography

0 No native plant populations remain
1 <25% of dominant native plant populations present and self-sustaining
2 25-50% of dominant native plant populations present and self-sustaining
3 50-75% of dominant native plant populations present and self-sustaining
4 75-90% of dominant native plant populations present and self-sustaining
5 90-98% of dominant native plant populations present and self-sustaining
6 Dominant native plant populations self-sustaining in a natural condition
9 Unable to assess native aquatic & wetland vascular plant population demography

BIO4b Native faunal demography

0 No natural faunal populations remain
1 <25% of native faunal populations present and self-sustaining
2 25-50% of native faunal populations present and self-sustaining
3 50-75% of native faunal populations present and self-sustaining
4 75-90% of native faunal populations present and self-sustaining
5 90-98% of native faunal populations present and self-sustaining
6 Native faunal populations self-sustaining in a natural condition
9 Unable to assess native aquatic & wetland faunal population demography

Human Influences

FHI1 Surface water quality

0 No flow
1 Very poor surface water quality
2 Poor surface water quality
3 Moderate surface water quality
4 Good surface water quality
5 Very good surface water quality
6 Excellent surface water quality
9 Unable to assess desired surface water quality

FHI2 Flow regulation

0 Flow refulation influences have eliminated or destroyed the springs
1 Very extensive flow regulation influences
2 Extensive flow regulation influences
3 Moderate flow regulation influences
4 Limited flow regulation influences
5 Very limited flow regulation influences
6 No flow regulation effects
9 Unable to assess flow regulation influences

FHI3 Road, Trail, and Railroad effects

0 Road, trail, or railroad influences have elimited the springs
1 Very extensive road, trail, or railroad influences
2 Extensive road, trail, or railroad influences
3 Moderate road, trail, or railroad influences
4 Limited road, trail, or railroad influences
5 Very limited road, trail, or railroad influences
6 No road, trail, or railroad influences
9 Unable to assess road, trail, or railroad influences

FHI4 Fencing effects

0 Negative influences of fencing have eliminated the springs
1 Very extensive negative influences of fencing
2 Extensive negative influences of fencing
3 Moderate negative influences of fencing
4 Limited negative influences of fencing
5 Very limited negative influences of fencing
6 No negative influences of fencing
9 Unable to assess influences of fencing

FHI5 Construction effects

0 Construction influences eliminated the springs
1 Very extensive negative construction influences
2 Extensive negative construction influences
3 Moderate negative construction influences
4 Limited negative construction influences
5 Very limited negative construction influences
6 No negative construction influences
9 Unable to assess construction influences

FHI6 Herbivore effects

0 Herbivory influences have eliminated the springs
1 Very extensive negative herbivory influences
2 Extensive negative herbivory influences
3 Moderate negative herbivory influences
4 Limited negative herbivory influences
5 Very limited negative herbivory influences
6 No negative herbivory influences
9 Unable to assess herbivory influences

FHI7 Recreational effects

0 Recreation influences have eliminated the springs
1 Very extensive negative recreational influences
2 Extensive negative recreational influences
3 Moderate negative recreational influences
4 Limited negative recreational influences
5 Very limited negative recreational influences
6 No negative recreational influences
9 Unable to assess recreational influences

FHI8 Adjacent lands condition

0 Ecological condition of adjacent landscape has eliminated the springs
1 Very extensive negative influences of adjacent landscape

Site______________________________ Date_____________

2 Extensive negative influences of adjacent landscape
3 Moderate negative influences of adjacent landscape
4 Limited negative influences of adjacent landscape
5 Very limited negative influences of adjacent landscape
6 No negative influences of adjacent landscape
9 Unable to assess influences of adjacent landscape

Administrative Context

AC1 Information quality/quantity
0 No information or map exists
1 Very limited mapping or other information
2 Limited mapping or other information exists
3 A modest amount of credible mapping and other information exists
4 Credible mapping and other scientific information exists
5 A great deal of high quality mapping and other information has been gathered and compiled
6 The springs is used as a research site, with much high quality information available
9 Unable to assess information quantity and quality

AC2 Indigenous significance
0 No significance as an indigenous cultural site
1 Virtually no evidence of indigenous cultural features or resources
2 One culturally significant feature or resource
3 Two or more culturally significant features or resources
4 Several culturally significant features or resources
5 Numerous indigenous culturally significant features or resources
6 Cultural significance essential for the well-being of one or more indigenous cultures
9 Unable to assess indigenous cultural significance

AC3 Historical significance
0 No historical significance
1 Very litle evidence of historically significant elements
2 One historically significant element
3 Two or more historically significant elements
4 Several historically significant elements
5 Numerous historically significant elements
6 Historical significance essential for the well-being of the culture
9 Unable to assess historical significance

AC4 Recreational significance
0 Desired effects of recreational use not achieved
1 Very extensive deviation from desired effects of recreational use
2 Extensive deviation from desired effects of recreational use
3 Moderate deviation from desired effects of recreational use
4 Limited deviation from desired effects of recreational use
5 Very limited deviation from desired effects of recreational use
6 No deviation from desired effects of recreational use
9 Unable to assess deviation from desired effects of recreational use

AC5 Economic value
0 The springs has no economic value
1 Very limited economic value
2 Limited economic value
3 Modest economic value
4 Considerable economic value
5 High economic value
6 Very high economic value
9 Unable to assess economic value

AC6 Conformance to mgmt plan
0 No management plan
1 Minimal management planning
2 Very preliminary management plan
3 Management plan exists, but receives little management attention
4 Management plan given moderate attention
5 Management plan given substantial management & legal consideration
6 Management plan fully implemented and followed
9 Unable to assess conformance to management plan

AC7 Scientific/educational value
0 No features of scientific or educational interest
1 One scientifically or educationally important feature
2 Two features of scientific or educational interest
3 Several features of scientific or educational interest
4 4-9 features of scientific or educational interest
5 At least 10 features of scientific or educational interest
6 Numerous features of scientific or educational interest
9 Unable to assess scientific or educational significance

AC8 Environmental compliance
0 No socioenvironmental compliance conducted or considered
1 Very little socioenvironmental compliance conducted or considered
2 Little socioenvironmental compliance

conducted or considered
3 Preliminary socioenvironmental compliance conducted
4 Socioenvironmental compliance undertaken, not yet completed
5 Socioenvironmental compliance completed, not enacted
6 Environmental compliance, and designation of critical habitat, is complete
9 Unable to assess environmental compliance

AC9 Legal status

0 No land, water, or ecosystem legal rights exist or are recognized
1 Rights may exist but have not been adjudicated or enforced
2 Rights exist but application for those rights/uses are pending; no enforcement
3 Rights exist and applications have been made; limited enforcement
4 Rights applications have been completed; moderately robust enforcement
5 Rights have been established; robust enforcement
6 Rights established and defended; legislative protection; robust enforcement
9 Unable to assess legal status

Risk

0 No risk to site
1 Negligible risk to site
2 Low risk to site
3 Moderate risk to site
4 Serious risk to site
5 Very great risk to site
6 Extreme risk to site
9 Unable to assess risk to site

Site________________________________ Date____________________

Information Source________________________ Cultural Radius (meters)__________

Cultural Values

Archaeological Value

0 No archaeological evidence present at or near spring
1 Almost no evidence of archeological remains near the spring
2 Minor evidence of archaeological artifacts near the spring (i.e., ceramics)
3 Moderate evidence of archaeological remains near the springs; hunting camp remains, potentially including hearth(s) but no dwellings evident
4 Artifacts, petroglyphs, minor ruins, and/or irrigation works are present, demonstrating fairly extensive prehistoric use of the site
5 Artifacts, petroglyphs, ruins, and/or water works, and dwelling sites are present, demonstrating extensive prehistoric use
6 Artifacts, petroglyphs, remains, and extensive ruins nearby, protected by the tribe due to great archaeological significance
9 Unable to assess archaeological value

Petroglyphs
Shrines
Walls
Jewelry
Ceramics
Flakes
Hearths
Ruins
Irrigation
Middens
Agriculture
Human Remains
Historical Archaeology
Other archaeology

Education/Knowledge Value

0 No knowledge of the site recorded in tribal history or academic records, and no information reasonably expected to exist
1 Knowledge of site expected to exist, but not available, no longer taught
2 Knowledge of site is documented but is minimal and not used in education or research
3 Moderate knowledge of site exists; is used to a moderate extent in education and/or as a research site
4 Fairly significant education and/or research significance
5 Very good educational and/or research significance, providing trans-generational knowledge
6 Outstanding educational and/or research significance; trans-generation knowledge; great concern about protecting site for educational purposes
9 Unable to assess educational or research significance

Youth education
Elder knowledge
Trans-generational
Culturally-specific
Academic research
Academic education
Non-academic education
Other knowledge

Ethnoecology

0 No record or presence of plant and/or animal species used for food, utilitarian, food, medicinal, ceremonial, or other purposes

1Former presence of ethnobiological resources, but no longer present, or very few ethnobiological resources
2 Only 1 ethnobiologically important species present, or only a few species that can readily be obtained elsewhere
3 Several ethnobiologically important species present, although they can be found elsewhere
4 Several ethnobiologically important species present, of which at least one is difficult to acquire elsewhere
5 Numerous ethnobiologically important species present, with one or more being unique to the site
6 Many ethnobiologically important species present, including many that cannot be found elsewhere
9 Unable to assess ethnobiologically important species

Plants

Used for food
Firewood, constr, etc.
Medicinal purposes
Ceremonial purposes
Extirpated species
Endangered species
Restoration potential
Multiple use/other

Animals

Used for food
Utility animals
Medicinal purposes
Ceremonial purposes
Extirpated species
Endangered species
Restoration potential
Multiple use/other

Ethnoecological processes

Ethnogeological processes

Dyes
Paints
Ceramics

Tribal/Band Historical Significance

0 History of the site has been lost and is not taught in neither academic nor non-academic settings

Site________________________________ Date________________

1 History of the site is very limited and poorly available
2 History of the site is limited, primarily available in unpublished reports (i.e., water resources, cultural preservation office, etc.)
3 History of the site is moderately available and not well known
4 Site history information availability is good and relatively widely known
5 Site history information availability is very good and quite widely known in both academic and non-academic settings
6 Site history information is excellent, and is taught by the elders to other tribal members in both academic and non-academic settings
9 Unable to assess tribal history of the site

Spring on Historic Route

Site Sacredness

0 No record of historical or contemporary site sacredness; no possibility of the site being sacred
1 Site sacredness is very minor; sacredness possible but not specifically recognized
2 Site sacredness is recognized, but has no specific sacred role or function
3 Site sacredness is moderate, related to one specific role or function
4 Site sacredness is fairly high, related to two specific roles or functions
5 Site is highly sacred, related to several specific roles or functions
6 Site is very highly sacred, related to many specific roles or functions
9 Unable to assess sacredness of site

Sacredness of water
Sacredness of traditional foods
Sacredness of materials
Sacredness of medicines
Sacredness of ceremonial substances
Sacredness of archaeological remains
Sacredness of stories
Spirits or divine beings
Passage point to/from other worlds
Significance in afterlife
Site is sacred
Site is sacred for its pristine character
Site important as route or waypoint

National Registry of Historic Places
NRHP Condition

0 Site has no potential for listing with the Tribe(s) or non-tribal agencies
1 Site has not been recognized by Tribe(s) as having potential for NRHP status, or has been recognized as having very little potential
2 Site has been recognized by the Tribe(s) and/or non-Tribal agencies as having low potential for NRHP status
3 Site has been recognized by the Tribe(s) and/or non-Tribal agencies as having moderate potential for NRHP status, but not formally proposed
4 Site is recognized and listed with the Tribe(s), and NRHP status has been proposed
5 Site is recognized and listed with the Tribe(s), and NRHP status is anticipated and pending
6 NRHP status has been fully completed with both the Tribe(s) and the federal government
9 Unable to assess NRHP potential

Application Status

0 No culturally significant properties exist
1 NRHP status application completed
2 NRHP application submitted
3 NRHP status pending acceptance of application
4 NRHP status approved, but process not complete
5 NRHP status approved
6 NRHP status established
9 Unable to assess NRHP process

Recognized by Tribe as worthy of listing
Recognized by agencies as worthy of listing
Application submitted and refused

Economic Value

0 No economic use or sale of springs resources
1 Very little economic value OR formerly of very limited economic value, but no longer used for agriculture, recreation, or ethnobiological economics
2 Low economic value; use or sale of springs resources depends on erratic availability of resources, weather conditions, etc
3 Moderate economic use(s) or value of springs resources, primarily for single family subsistence; limited financial benefits to larger community
4 Good economic uses and sale of springs agricultural, recreation, and/or ethnobiological resources to the Tribe and/or external communities
5 Very good economic uses and sale of springs' agricultural, recreation, and/or ethnobiological resources to the Tribe and/or external communities
6 Tribe receives excellent financial benefits from the use(s) and sale of springs agricultural, recreation, non-use, and/or ethnobiological resources
9 Unable to assess economic value to the Tribe and/or external communities

Single family use/sales
Communal use/sales
Tribal use/sales
Livestock support
Potable water
Irrigation water

Site________________________________ Date________________

Mineral extraction
Mining permits
Electrical power
Recreational visitation
Non-agricultural plants
Non-agricultural animals
Aquatic agric. plants
Wetland agric. plants
Nonhunted ethnofaunal
Native fish
Farmed fish
Fishing permits
Wildlife
Hunting licenses
Real estate
Non-use values
Other economic values

Tribal Legal Significance

0 No legal interest or consideration of the site's resources
1 Little to no legal status; very little outside interest
2 Very low legal status; little outside interest
3 Moderate legal significance – some outside interest
4 Legal status is fairly well established, and the site is fairly well protected
5 Site legal status is clearly established, and may apply to more than one Tribe
6 Site legal status very clearly established; legal standing is an important precedent
9 Unable to assess legal status

Tribal—individual
Tribal-clan
Tribal
Tribal—multicultural
State
Federal
Agency
Other

Tribal Contemporary Use

o Tribal use or non-use value
1 No direct use but may have potential or non-use value
2 One minor use and may have potential non-use value
3 Slight use—2 uses plus some non-use value
4 Moderate use—3-5 uses plus some non-use value
5 Much use—5-7 uses plus some non-use value
6 Extensive use—8 or more uses and non-use value
9 Unable to assess tribal use or non-use value

Tribal water use
External water use
Irrigation use
Agricultural use
Ceremonial use
Fishing use
Hunting use
Gathering use
Educational use
Mineral extraction
Fuel use
Energy use
Aesthetic use
Recreational use
Guiding visitation use
Route in use