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U.S. National Park Service
Mojave Inventory and Monitoring Network
Spring Survey Protocols: Level I

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Introduction

Background

Thousands of springs scatter a variety of landscapes throughout the western U.S. They have been a focus of human activity for thousands of years because they often provide the only reliable source of water. Their importance as aquatic and riparian habitats has become increasingly apparent over the past 70 years (Hubbs 1995), and they are now known as "biodiversity hotspots" that support a large proportion of the aquatic and riparian species in arid regions (Fisher et al. 1972, Williams and Koenig 1980, Gubanich and Panik 1986, Myers and Resh 1999). Several hundred species or subspecies of fishes, mollusks, crustaceans, aquatic insects, and plant species are endemic to western U.S. springs, which demonstrates their importance to a wide variety of plants and animals that do not occur elsewhere (e.g., Hubbs and Miller 1948, Hubbs et al., 1974, Williams et al. 1985, Minckley et al. 1986, Wiggins and Erman 1987, Hershler and Sada 1987, Shepard 1990, Hershler 1998 & 1999, Schmude 1999, Hershler and Frest 1996, Baldinger et al. 2000, Polehmus and Polhemus 2002, Sada and Vinyard 2002, Smith et al. 2002).

Although many western U.S. springs have been surveyed to determine discharge rates and aquifer affinities, broad-scale and biological surveys have been uncommon, and knowledge of spring ecosystems is very limited. Biological studies in other regions have shown, however, that a number of anthropogenic uses and physicochemical factors influence the biotic characteristics of springs. While many springs are comparatively harsh environments, the adverse influences of anthropogenic uses have caused spring biota to experience the highest rate of extinction known in the western U.S. (Williams et al. 1985, Shepard 1993, Sada and Vinyard 2002). Programs are needed to more thoroughly understand the effects of disturbance on spring biota and moderate the effects of anthropogenic uses to prevent additional resource loss and restore spring habitat quality.

Purpose

Resource agencies are challenged to design, implement, and achieve management goals. These goals are usually identified during a planning process that requires information that is compiled at several different levels of intensity. Planning first involves accumulating information that identifies and characterizes resources within a defined geographic area (e.g., within a National Park, a U.S. Bureau of Land Management Resource Area, a National Forest, etc.). This information may include both quantitative and qualitative data. When conducted properly, this phase provides initial insights about resource condition, the response of resources to current management practices, and some potential management options. If resource conditions do not meet management goals and guidelines, this phase should be followed by surveys that address particular management challenges. This often involves compiling a higher level of quantitative data that can be used to assess the affect of management and resource use across a broad area. A third level of more quantitative information may be needed to address individual resource issues, which require long term monitoring, public involvement, or legal challenges.

Since most State and Federal agencies have a weak understanding of spring resources under their jurisdiction, surveys and survey protocols are needed to compile appropriate information that will assist with their management. Following requirements for planning and management that are summarized above, three levels of surveys can be described to assist the National Park Service with spring management challenges. These protocols are intended to describe biotic and abiotic characteristics of springs and accomplish the following goals:

Level I spring surveys are designed to identify and characterize spring resources, delineate the distribution of important species and salient aspects of their habitat, and to determine unique resource challenges. This protocol provides effective methods to characterize spring systems across the landscape, and information that can be used to set management and restoration priorities (see Management and Restoration Priorities section). However, comparison of springs and assessment of management actions should be restricted to geographic areas where local springs are influenced by common water sources, climates, and geologies. In this light, it is inappropriate to compare springs in Great Basin National Park with springs in Death Valley National Park, but comparison of springs within each park would probably be appropriate. This protocol is based on work conducted in southern Nevada by Sada and Nachlinger (1996, 1998) and Bradford et al. (in press), and many additional springs throughout the intermountain west (e.g., Meffe and Marsh 1983; Sada et al. 2000; Sada 2001a,b; Sada and Herbst 2000). Data elements recorded during these surveys are as follows (a sample data sheet is shown in Appendix B):

Level I Surveys

Locate and provide reconnaissance level characterization of biotic and abiotic features of spring habitats throughout a jurisdictional area, and determine the presence or absence of rare aquatic species.

Level II Surveys

Qualitatively sample riparian and aquatic communities to determine community structure, and quantitatively sample salient physicochemical elements to identify aquifer affinities.

Level III Survey Protocol

Quantitatively sample additional physicochemical elements to determine aquifer dynamics. Quantitatively sample riparian and aquatic communities and habitats to determine spatial and temporal variation in environmental and biotic (e.g., abundance and community structure) characteristics, and to quantitatively determine biotic and abiotic interactions.

Foundations for these protocols are provided by a number of hydrological and biological studies of springs in the western U.S. and elsewhere (e.g., see Ferrington 1995, Botosaneau 1998, Meffe and Marsh 1983, Thomas et al., 1996, Sada and Nachlinger in review, and many other references that are cited in this report) that have examined physicochemical conditions of springs and relationships between their abiotic and biotic characteristics. Level I protocols and methods to

use information they provide are described in this summary. Similar detail for Level II and III protocols will be described in later summaries.

These protocols also summarize the ecology of rare aquatic species that may occur in springs. This information should facilitate sampling and make it easier for surveyors to determine their presence or absence.

Spring Systems

Aquifer Sources

Springs are relatively small aquatic and riparian systems that are maintained by groundwater flowing onto the land surface through natural processes (Hynes 1970). They are distinctive for several reasons: their water temperature is relatively constant (at least near their source), they depend on subterranean flow through aquifers, they provide the only water over vast areas and are therefore "biodiversity hotspots" (Myers and Resch 1999), and they often support species that occur only in springs (Hynes 1970, Erman and Erman 1995, Myers and Resch 1999).

Springs are supported by precipitation that seeps into the soil and accumulates in aquifers where it is stored. They occur where water reaches the earth's surface through fault zones, rock cracks, or orifices that occur when water creates a passage by dissolving rock. Spring hydrology is influenced by the characteristics of regional and local geology, and how water moves through an aquifer. The size of an aquifer depends on regional and local geology and climate. There are three general types of aquifers that supply springs in the Mojave Network.

Perched Aquifers

In the western U.S., springs at high elevations (> 1800 m) springs are generally supplied by perched aquifers. These springs are cool (<20°C) and they are recharged by precipitation from an adjacent mountain range. Perched springs are usually small and they often dry up during the fall.

Local Aquifers

Springs fed by local aquifers are also cool (<20°C) and fed by precipitation from an adjacent mountain range. Local aquifers are also comparatively small and shallow, and the amount of water discharging from their springs may change seasonally and annually in response to local precipitation. They are quickly recharged, typically by annual precipitation on individual mountain ranges or over a small area. Highest flows occur during the spring and early summer when aquifers are recharged by snowmelt. Springs supplied by local springs usually only dry during extended droughts.

Regional Aquifers

Springs fed by regional aquifers are warm (>20°C) and generally are supplied from several recharge sources that may extend over vast areas. Flow through these aquifers is complex,

controlled by fractures, and in many areas the flow extends beneath several valleys and topographic divides (Mifflin 1968, Winograd and Thordarson 1975, Thomas et al. 1996). In contrast, discharge from regional springs is constant over long periods (often >1,000 years, and exceeding 600,000 years; Winograd et al. 1992).

Physical Characteristics of Springs

Springs and seeps occur in many sizes and shapes. Seeps are small springs that support small amounts of riparian vegetation that is adapted to drier conditions, and they often dry on a regular basis. Springs may also be small but they have larger aquatic habitats, dry less frequently, and generally support larger riparian zones with species that rely on moist soils. Springs are frequently categorized by the morphology of their source. *Limnocrenes* are sources where water flows from large deep pools, *helocrenes* are marshy and bog-like, and *rheocrenes* flow into a confined channel.

Each spring and seep is a unique combination of physical and chemical conditions (see Hynes 1970, Garside and Schilling 1979). They can be cold (near or below mean-annual air temperature), thermal (>5°C and <10 ^{o}C above mean-annual air temperature [van Everdingen 1991]), or hot (water temperature >10°C above mean-annual air temperature [Peterken 1957]). Springs may also be chemically harsh. Many hot springs are highly acidic and springs flowing through limestone and basalt may be alkaline. Dissolved oxygen concentrations are frequently very low (<2 parts per million (ppm)) in hot springs, and high (>5 ppm) in cooler springs. At spring sources, dissolved oxygen concentrations are frequently low and increase downstream with exposure to the atmosphere (Hynes 1970). Electrical conductance may also range from very low (near 0 µmhos) to very high (>10,000 µmhos) in some harsh environments. Also, cooler and smaller springs may freeze during winter, while larger and warmer springs do not.

Springs occur singly and in provinces that include many sizes and morphologies. Most springs below approximately 2,100 meters (7,000 feet) in western North America are isolated and flow a short distance before drying (Deacon and Minckley 1974). Many arid-land springs also dry periodically. Other springs flow into rivers, lakes, and streams, and spring provinces may support extensive wetlands. Springs in Clark County include all varieties of isolation and connectivity.

Biological Characteristics of Springs

The physical, chemical, and disturbance characteristics of a spring are the most dominant factors influencing its riparian and aquatic plant and animal communities (van der Kamp 1995, Sada and Nachlinger in review). Riparian vegetation at cool water springs and springs with lower thermal temperatures consists of species that also occur near regional streams, lakes, and marshes (e.g., willows, mesquites, sedges, and grasses). This vegetation may be dense at springs that have been minimally affected by conflicting uses. Springs that have been highly modified usually have less diverse riparian communities that may include non-native species and species that are typically associated with upland plant communities. Riparian vegetation along springs may be restricted to the immediate boundaries of the aquatic habitat, or it may extend outward for substantial distances. Narrow riparian zones are typically dominated by sedges, grasses, and

woody phreatophytes (e.g., willows, mesquite, etc.). Wider riparian systems generally occur at spring provinces where water seeps outward from aquatic habitats and moistens hydric soils.

The complex influences of the physical and chemical environment on plant and animal physiology cause most springs to be biologically distinct. Species that inhabit rheocrenes prefer flowing water and species in limnocrenes are more similar to species that occupy lakes and ponds (Sada et al. 2000). Aquatic communities in spring sources also differ from communities further downstream. Many spring source species do not occupy downstream habitats where temporal fluctuations in water temperature and flow are greatest (Erman and Erman 1990, Erman 1992). Communities in permanent springs generally include more species and more individuals than communities in ephemeral springs (Erman and Erman 1995). Ephemeral springs and springs with harsh environments generally have low species richness, and aquatic species in ephemeral habitats are typically vagile (animals that can fly or crawl long distances) and well adapted to inhabiting intermittent aquatic habitats. Springs occupied by endemic aquatic species do not dry, and they have persisted for thousands of years. These endemic species are poorly vagile and they cannot easily move across dry land.

Smaller springs are generally autotrophic aquatic systems that depend little on allochothonous carbon sources (Minshall 1978, Cushing and Wolf 1984). In larger springs, energy may enter the aquatic system during periodic floods that flush carbon from the surrounding landscape. Plant and animal assemblages in springs are also similar to aquatic and riparian assemblages associated with streams and ponds. However, they exhibit diverse compositional and structural characteristics that are unique. Springs with harsh environments (e.g., high water temperatures, high concentrations of dissolved solids, subject to scouring floods or periodic drying, etc.) are biologically depauperate in comparison to springs with cooler, purer water. Life within and surrounding harsh environments is limited to animals and plants that are able to tolerate conditions where osmoregulation and respiration are difficult (Brock 1994, Kristijansson and Hreggvidsson 1995). In montane Sierra Nevada springs Erman and Erman (1995) found species diversity was correlated with spring permanence, calcium concentration, specific conductance, pH, magnesium, and alkalinity. Flies (Diptera) are the most common animals in harsh environments and bluegreen algae (Cyanobacteria) frequently dominate the vegetation community of hot springs. In cooler habitats where conditions are moderate, stoneflies (Plecoptera), mayflies (Ephemeroptera), and caddisflies (Trichoptera) are common components of the aquatic fauna. Sada and Nachlinger (1996, 1998) also found that spring size and habitat conditions influence the biodiversity of southern Nevada springs. Aquatic and riparian communities at larger springs and springs that had been minimally altered had greater biodiversity than communities at small and highly disturbed springs.

Most spring environments are less variable than other aquatic habitats (e.g., streams, rivers, and lakes), which cause variability in population size and assemblage structure to be comparatively low (Minckley 1963, van der Kamp 1995). Within a spring system, environmental variation is typically lowest near the source where environments are comparatively stable and it is greatest downstream where variability in temperature, discharge, dissolved oxygen concentration, and other factors is much greater (Deacon and Minckley 1974). As a result, the composition of source and downstream communities are usually different, and species that occupy the source usually prefer habitats that are unique to this area and they are frequently absent from

downstream habitats (Hayford *et al.* 1995, Hershler 1998, O'Brien and Blinn 1999). There are also seasonal differences in abundance that are influenced by mostly by temperature and photoperiod. Resh (1983) found more species near the source of a Mendocino County, California spring, but higher animal density in downstream reaches. In a small New Mexico spring, Noel (1954) found the highest density was near the source and during the period January through September. Abundance also differs throughout the year in response to food availability, temperature, reproduction, and migration of species along a springbrook (Minckley 1963, Glazier and Gooch 1987, Varza and Covich 1995).

Although additional information is needed to identify habitats preferred by endemic macroinvertebrates, it appears that these species prefer specific habitat types. Springsnails in the genus *Pyrgulopsis* generally prefer gravel substrate and flowing water, whereas species in the genus *Tryonia* occur in sand substrate that is typically found along banks in slow current (Hershler 1998, Hershler and Sada 1987, Sada and Herbst 1999). Endemic beetles (e.g., *Stenelmis* sp. and *Microcylleopus* sp.) and bugs (e.g., *Ambrysus* sp. and *Limnocoris* sp.) are most common where gravel substrate occurs with high current velocities (Sada and Herbst 1999). Populations of these endemic taxa represent relict populations that became established during ancient pluvial periods over the past several million years (Taylor 1985, Hershler and Pratt 1990). These taxa occur only in springs that have provided continuous aquatic habitat since ancestral forms first established and that have not been severely altered. These springs are reliable water sources that can be used for both conservation and public use when development programs are properly designed.

Because of the relative isolation, relict nature, and water at springs, the plant diversity and endemism are high compared to adjacent uplands. Sada and Nachlinger (1996) documented 250 species of plants and animals associated with springs in the Spring Mountains of southern Nevada. Comparatively high species diversity (126-150 species) was also recorded at springs along the southwestern edge of the Great Basin in Owens Valley, California (DeDecker 1980, Ferren et al. 1991). Springs in both of these regions also support rare plant populations (Skinner 1994, Sada and Nachlinger 1998).

Spring systems also may exhibit unusual hydrologic and edaphic characteristics that are associated with plant rarity. For example, soils near many Great Basin springs are highly alkaline with high levels of calcium, an element frequently associated with rare plants in the genus *Astragalus* (milk vetch) (Ferren et al. 1991). In Nevada, approximately 15 wetland plants are on Sensitive or Watch Lists (Nevada Natural Heritage 1998), and in the Great Basin region of eastern California (Mono and Inyo Counties) approximately 35 wetland plants are considered rare (Skinner 1994).

Comparatively little information has been compiled to show the value of spring-fed riparian habitats to western North American birds, reptiles, amphibians, and mammals. However, extensive work in riparian habitats along streams and rivers indicates their importance for roosting, food, and shelter (e.g., Warner and Hendrix 1984, Johnson et al. 1985, Naiman and Rogers 1997). Quality riparian habitat has high structural diversity created by dense undergrowth of tangled vegetation and debris. In quality habitat, vegetation at mid-level is less dense and there is a comparatively open canopy provided by large trees. In many of western

North America's riparian zones, structure provided by a dense undergrowth of shrub willow and debris, willows at mid-level, and a willow and cottonwood tree canopy. Mesquite (*Prosopis* spp.) woodlands are also common at lower elevations and latitudes in arid lands (Hendrickson and Minckley 1984). Riparian habitat has been reduced at many western U.S. springs by diversion, burning, vegetation control, and excessive ungulate grazing (Shepard 1993). As a result, suitable riparian habitat along springs has been eliminated or degraded so that invasive species such as brown-headed cowbirds (*Molothrus ater*) can more easily invade nesting areas (Gaines 1977).

The amount that birds depend on water for drinking appears related to their dietary habits and behavior. Granivorous birds drink more than carnivorous or insectivorous birds (Fisher *et al*. 1972). Williams and Koenig (1980) suggested that western tanagers (*Piranga ludoviciana*) in central California depend on springs during migration but Gubanich and Panik (1986) rarely recorded this species drinking from springs in western Nevada. Gubanich and Panik (*ibid*) did, however, observe insectivorous species such as American robin (*Turdus migratorius*), Townsends solitare (*Myadestes townsendi*), mountain bluebird (*Sailia currocoides*), northern flicker (*Colaptes cafer*), and horned lark (*Eremophila alpestris*), and five species of warbler drinking from springs. Both of these studies suggested that the stresses of migration may cause insectivorous and frugivorous species to be at least seasonally dependent on spring water.

Birds are highly vulnerable to predation while drinking and traveling to and from water (Fisher *et al*. 1972). Gubanich and Panik (1986) compared use at two springs with different amounts of cover, and concluded that birds more frequently used the site with greater tree and shrub cover. Species such as rufous-sided tohee (*Pipilo erythrophthalmus*), red-breasted nuthatch (*Sitta canadensis*), mountain chickadee (*Parus gambeli*), shrub jay (*Aphelocoma coerulescens*), and stellers jay (*Cyanocitta stelleri*) were never observed drinking away from cover. They also observed many instances of birds seeking cover in trees and shrubs near springs when avian predators appeared.

Spring-fed riparian habitats are also used by other vertebrates, some of which are endemic to small areas. Hall (1946) and Ingles (1965) identified voles endemic to spring-fed mesic alkali wetlands in desert regions, and Myers (1942) and Schuierer (1963) identified endemic toad populations in the southwestern Great Basin. Many species of bats also use water and insects provided by springs (O'Farrell and Bradley 1970, 1977).

Rare Species

Taxonomic studies over the past 140 years have found a large number of endemic plants and animals in wetlands throughout the Intermountain Region (see Miller 1958, Taylor 1985, Hershler 1998). Early studies focused on lotic habitats and large, valley floor springs that were inhabited by unique fishes. More recent studies have examined macroinvertebrates in small springs. A diverse crenobiotic (obligate spring-dwelling) fauna is now known to occupy isolated habitats throughout much of the western U.S. These species represent relict populations that have persisted in isolated habitats for thousands of years. They are unable to live outside of an aquatic environment for long periods and most of them are restricted to springs with good water quality. They never inhabit springs that periodically dry. Therefore, extant populations are in

aquatic habitats that have persisted (possibly in conditions similar to those we see today) for long periods of geological time (Taylor 1985, Polhemus and Polhemus 2002). The Great Basin supports a particularly extensive aquatic fauna that includes approximately 125 endemic species (two amphibians, 28 fish, eight insects, one fairy shrimp, and 85 mollusks, and two amphipods) and 45 subspecies (one aquatic insect and 44 fish) (Sada and Vinyard 2002). The importance of springs to rare species indicates that survey protocols should include methods to determine their presence or absence at each spring.

While there have been few descriptions of new fish taxa in arid lands of the western U.S. within the past 20 years, more than 100 species of aquatic mollusks, crustaceans, and insects (e.g., Hershler and Sada 1987, Shepard 1990, Polhemus and Polhemus 1994, Hershler 1998 & 1999, Schmude 1999, Hershler and Frest 1996, Weaver and Myers 1998, Baldinger et al. 2000) have been described from smaller springs over the past 15 years. Most of these springs are small and not occupied by native fishes. Finger clams (*Pisidium* spp.) and amphipods (*Hyalella* spp. and *Gammarus* spp.) also occur in many springs. Taxonomy of these groups is poorly understood, and future studies may result in description of new species.

Surveys for rare fishes have been comparatively extensive. They have included most large spring habitats and streams, and opportunities for finding new populations are comparatively small. However, the number of recently described aquatic macroinvertebrates from single localities and the number of habitats that have not been surveyed both suggest that additional new species will be discovered. Table 1 shows taxonomic groups that are most likely to include crenobiontic macroinvertebrates in arid lands of the western U.S. (see Myers and Resh 1999, Hershler and Hershler 1998 & 1999, Polhemus and Polhemus 2002, Sada and Vinyard 2002).

Descriptions of new springsnail species are notable among recent taxonomic work because their diversity is surprisingly high (e.g., Hershler 1998). Importance of this fauna has been formalized in a MOU for Great Basin springsnail conservation, which was signed by The Nature Conservancy, Smithsonian Institution, Department of Interior (FWS, BLM, NPS, and USGS), and U.S. Forest Service during 1998.

Table 1. Taxonomic groups of crenobiontic aquatic macroinvertebrate that most commonly occur western U.S. springs.

Aquatic Insects
Order Coleoptera
Family Elmidae (riffle beetles)
Order Hemiptera
Family Naucoridae (naucorid bugs)
Order Trichoptera
Family Lepidostomatidae (caddisflies)
Mollusks
Family Hydrobiidae (springsnails)
Crustaceans
Order Amphipoda (scuds)

These species occupy a wide variety of habitats, and they may be very scarce or abundant. All of these species can be easily captured using a kitchen sieve to collect animals from aquatic vegetation, debris, or the substrate. Each species prefers a distinctive microhabitat, and sampling must include collection from all of the habitat types found in a spring. They are usually most abundant within 50 m of a spring source, and scarce or absent from the downstream-most reaches of the aquatic habitat. To facilitate field identification, drawings and photos of representative animals in these groups are shown in Sada et al. (2001).

Anthropogenic Factors

Most springs in western North America have been physically and biologically modified from historical conditions that existed when settlers first entered the region (Shepard 1993). Many changes occurred when settlers developed springs as water sources for their homes and livestock. Other changes accompanied the introduction of non-native plants and animals. Habitats were also altered by livestock, wild horse, and burro grazing and trampling. Influences of these impacts have been similar to effects of excessive grazing observed in other regions (Kauffman and Krueger 1984, Fleischner 1994) where it has often degraded riparian vegetation, and increased water temperature and the amount of fine substrates. Spring waters have also been piped, spring brooks channelized, and excessive ground water withdrawal has affected spring biota by decreasing habitat size (even drying some habitats) and vegetative cover, and changing aquatic and riparian community composition (see Miller 1961, Dudley and Larson 1976, Miller et al. 1989, Hershler 1998). Other changes accompanied introductions of non-native plants and animals, which resulted in loss of native species through competitive interactions and predation. Spring and stream ecosystems respond to these biological and physical perturbations in similar ways. Aquatic and riparian habitats can be degraded or eliminated through water diversion, intense ungulate grazing, and non-native plants. Altering riparian vegetation may alter energy budgets (changing the aquatic system from being allochthonous to autochthonous) and reducing larval food and reproductive habitats for terrestrial phases of aquatic insects, which are important food for many bird species (Erman 1984, 1987). Similar results may occur following establishment of non-native species that are predaceous or competitively superior.

Non-Native Species

A number of non-native aquatic species also occur at springs. Fishes occur mostly in larger habitats, while macroinvertebrates may occupy a wide variety of spring sizes and types. The most common non-native aquatic animals known from Great Basin and southern California springs are shown in Table 2. Non-native plant species are also known from springs. Salt cedar (*Tamarix* spp.) and arundo (*Arundo donax*) are the most common species that may alter riparian systems. Rabbit's foot grass (*Polypogon monspeliensis*), Russian knapweed (*Acroptilon repens*), and white-top (*Cardaria pubescens*). Refer to Bossard et al. (2000) and Whiston et al. (1992) for additional information and plant identification information.

Table 2. Common non-native aquatic species known from Great Basin and southern California springs.

Fishes
Mosquito fish (*Gambusia affinis*)
Goldfish (*Carassius atratulus*)
Amphibians
Bullfrogs (*Rana catesbeiana*)
Mollusks
Red-rimmed melanoides (*Melanoides tuberbulata*)
New Zealand mudsnail (*Potamopyrgus antipodarum*)
Crustaceans
Order Decapoda (crayfish)

Level I Spring Survey Protocol Guidelines

Level I spring surveys are designed to identify and provide reconnaissance level characterization of spring resources, delineate the distribution of important species and salient aspects of their habitat, and to determine unique resource challenges. This protocol provides effective methods to characterize spring systems across the landscape, and information that can be used to set management and restoration priorities (see Management and Restoration Priorities section). However, comparison of springs and assessment of management actions should be restricted to geographic areas where local springs are influenced by common water sources, climates, and geologies. In this light, it is inappropriate to compare springs in Great Basin National Park with springs in Death Valley National Park, but comparison of springs within each park would probably be appropriate. This protocol is based on work conducted in southern Nevada by Sada and Nachlinger (1996, 1998) and Bradford et al. (in press b), and many additional springs throughout the intermountain west (e.g., Meffe and Marsh 1983; Sada et al. 2000; Sada 2000b; Sada and Herbst 2000). Data elements recorded during these surveys are as follows (a sample data sheet is shown in Appendix B):

Record the following information at the spring source, and include the upper 50 m of aquatic habitat (at larger springs) in the survey. All aquatic habitat should be include for springs with spring brooks less than 50 m long.

- Record the date that the spring survey is conducted

- Identify personnel conducting this spring survey, and list a field note number.

- Record the State where the spring being surveyed is located.

- Record the County where the spring being surveyed is located.

- Record the drainage basin where the spring is located. In the Great Basin, this consists of identifying the valley where the survey is being conducted, in regions with large basins, record the river basin. If in doubt about the location, record names of both the valley and river basin.

- Record Township, Range, and quarter-section coordinates.

- Record the 1:100,000 scale U.S. Geological Survey map that includes the spring/seep location, the 1:24,000 topographic map may also be recorded.

- Record Global Position System location (NAD 27) of the spring/seep source. Either UTMs (to the nearest meter) or Latitude/Longitude (to the nearest second) may be used according to local convention. Computer programs are available to convert between these units. Also record PDOP to indicate the accuracy of these coordinates

- Record whether or not the spring/seep can be accessed by vehicle. Record 'positive' if a road leads to the spring so that it can be reached by passenger car or 4 X 4, or 'negative' if no road exists. Exceptions to this are situations with historical road access but current access is blocked by flood, avalanche, etc. damage. In these situations cite that vehicle access is '+' and record in the notes that current access is blocked for the observed reason. The '+' notation is important because it is highly likely that the spring/seep was disturbed during historic vehicle access.

- Record whether or not photos are taken of the spring/seep. Photos should be labeled by field note number, date, site name and Township, Range, quarter Section location. Photos should be taken using a digital camera, or slides and positive exposures should be scanned and digitally saved.

- Record spring elevation in feet or meters (preferred). Measurement should be taken using GPS system (preferred). A Thomen altimeter (accuracy + 30 feet) may also be used but elevation should be calibrated from maps as frequently as possible during each day that fieldwork is conducted. Methods used to record elevation should be mentioned in comments portion of data sheet.

- Record land ownership as U.S. Forest Service, U.S. Bureau of Land Management, Tribal, Military, Private, or other (e.g., State lands, U.S. Fish and Wildlife Service, municipality, etc., write out the name of the owner)

- Record spring type as: Rheocrene (a spring that discharges into a defined channel), Limnocrene (a spring that discharges into a ponded or pooled habitat before flowing into a

Helocrene (similar to a Limnocrene, but marshy and comparatively shallow, not an open pond or pool).

- Estimate Spring Discharge in liters/minute. When possible, measure discharge by recording the length of time required to fill a container with a known volume. However, the small size of most arid land springs makes it difficult to accurately measure discharge. In most of these systems, it is not possible to capture all discharge or to measure current velocity using a meter or other methods. Also, daily and seasonal variation in discharge may be great, which suggests that estimates during a single survey may minimally describe long term discharge characteristics.

- Estimate Spring Brook Length by measuring (or pacing) the distance (in meters) from spring source to the downstream extent of surface water.

- Estimate average Water Depth (the vertical distance from substrate to water surface, in centimeters) that is found throughout the aquatic habitat.

- Estimate the average Wetted Perimeter Width (the length of wetted contact between flowing or standing water and the spring brook bottom in a vertical plane at right angles to the direction of flow, in centimeters).

- Measure Dissolved Oxygen Concentration (D.O., in mg/liter) using a field meter (e.g., YSY, Oakton, etc.). The meter should be kept clean, with fresh batteries, and calibrated daily following the manufacture's recommendation. All water chemistry paratmeters should be measured as close to the spring source as possible and in flowing water if available. The location of the measurements not taken at the source should be noted.

- Measure Water Temperature. This measurement is easily taken with a meter used to measure D.O. or conductivity.

- Measure Conductivity (electrical conductance, in µmhos or microsiemens) using a field meter (e.g., YSY, Oakton, etc.). The meter should be kept clean, with fresh batteries, and calibrated daily following the manufacture's recommendation.

- Measure pH using a hand-held field meter that can be calibrated (such as Oakton Model, pHtestr2). The meter should be kept clean, with fresh batteries, and calibrated daily following the manufacture's recommendation. These meters generally have a limited life, and a backup meter should always be carried.

- Qualitatively estimate the percent of Emergent Cover (vegetative, debris, or other material that arises within the wetted perimeter).

- Qualitatively estimate the percent of Vegetative Bank Cover (live vegetation that covers spring brook banks within the riparian zone).

- Qualitatively estimate Spring Brook Bank Incision. Rate banks as being incised when bank angle > 60° from vertical, and not incised when bank angles are > 60° from vertical. For spring brooks, bank incision is generally an indicator of stability and the absence of trampling activities.

- Qualitatively estimate Spring Brook Bank Stability (the resistance or susceptibility of the spring brook channel and banks to erosion) as poor, medium, or good (on a scale of 1 to 3 with 1 being the most stable banks).

- Qualitatively estimate the Percent of the Wetted Perimeter Covered by Watercress (*Rorippa nasturtium-aquaticum*).

- Qualitatively estimate Substrate Composition using a Wentworth particle scale analysis, which describes the substrate by the proportional composition of materials, where materials are classified as: Fines (<1 mm), Sand (1 mm - 5 mm), Gravel (>5 mm - 80 mm), Cobble (>80 mm - 300 mm), Boulder (>300 mm), or bedrock. Size is defined as the minimum particle size of substrate as measured on a two-dimensional axis, as would pass through a substrate sieve.

- Note presence of the following groups of animals, and identify the species, if possible: springsnails, fish, amphibians, pulmonates (e.g., *Juga*, *Physa*, etc.), amphipods, clams, and other notable animals.

- Estimate Site Condition and identify influences causing disturbance. Sites should be categorized undisturbed, slightly disturbed, moderately disturbed, or highly disturbed by cultural or natural factors. These evaluations should follow these guidelines:

  1. Springs can be disturbed by natural and cultural factors, which appear to have similar effects on aquatic and riparian communities. Natural and slightly disturbed springs have generally higher species richness and fewer non-native species than moderately and highly disturbed springs. Most springs in southern Nevada have been affected by cultural factors, including trampling by non-native animals (mostly cattle, wild horses and burros, and elk), diversion (often including a spring box that is placed into spring sources to capture water in a pipe and divert it to an off-site location), and recreation (which often includes diversion, trampling, and off-highway vehicle travel). Natural disturbance factors include fire, scouring floods (particularly at springs lying in arroyos), avalanche (high elevation springs), and drought. Ephemeral springs and seeps are considered as highly disturbed by the natural event of drought.

  2. Site condition is assessed by categorizing the amount of disturbance that can be attributed to each cause of disturbance, which is scaled on a ranking from 1 (undisturbed) to 4 (highly disturbed) that are assigned according to the following criteria:

  3. Undisturbed sites appear unaffected by historical or recent activity. Dry springs or intermittent seeps and springs are not classified as undisturbed because the disturbance of drought has an overwhelming influence on aquatic communities. These springs do not

4. Slightly disturbed sites exhibit little evidence that vegetation or soil had been disturbed. Vegetation shows slight signs of browsing and foraging, and animal footprints and scat are prominent. These springs are ranked disturbance category 2.

5. Moderately disturbed sites exhibit evidence of recent disturbance. Vegetation covers > 50% of the spring brook banks, and at least 50% of natural discharge remains within the natural spring brook. Neither the spring or spring brook has been impounded, and non-native species do not dominate aquatic or riparian communities. These springs are ranked disturbance category 3.

6. Highly disturbed springs either have < 50% of their banks covered by vegetation, spring brooks containing < 50% of natural discharge, or they are impounded or dredged. Ephemeral springs are categorized as highly disturbed because of recent flow reduction. These springs are ranked disturbance category 4.

7. Human disturbance -- Qualitative estimate indicating the amount a spring has been disturbed by human-caused influences. Human-caused factors included impacts from management that include all factors attributed to the influence of humans. These consist of effects from non-native animals (e.g., cattle, wild horses, wild burros, and elk), diversion (municipal, domestic, and for livestock), and recreation. Multivariate analyses examined species-environmental relationships two ways, one by combining all human disturbances and the second by separating out each type of disturbance. Human Disturbance Categories were ranked as described above under 'Disturbance'.

Natural disturbance -- Qualitative estimate indicating the amount a spring has been disturbed by natural events. Fire, flood, and avalanche were the only natural disturbance factors observed in the Spring Mountains. Multivariate analyses examined species-environmental relationships two ways, one by combining all natural disturbances and the second by separating out each type of disturbance. Natural Disturbance Categories were ranked as described above under 'Disturbance'.

Management and Restoration Priorities

Prioritization

Information compiled during Level I surveys provides insight into the biotic potential of each spring, which facilitates the identification of management and priorities. The foundation for this assessment lies in the most comprehensive examination of biotic and abiotic relationship in springs across a western U.S. landscape by Sada and Nachlinger (in review). They found that

riparian and aquatic macroinvertebrate communities in springs were most strongly influenced by elevation, spring size (ergo discharge, spring brook length, wetted perimeter width, etc.), water temperature, and disturbance. Larger, higher, colder and less disturbed springs all supported greater riparian and aquatic species richness than lower, warmer, and more disturbed springs. The number of obligatory and facultative wetland plant taxa in the riparian community was also lower in more disturbed sites, and the number of exotic and upland plants was greater at moderate and highly disturbed sites. Macroinvertebrate taxonomic richness and the abundance of Ephemeropterans (mayflies), Plectoperans (stoneflies), and Trichopterans (caddisflies) were correlated. These taxonomic groups were also less abundant in small, warm, low elevation, and highly disturbed springs, and communities in these habitats were dominated by taxa that characterize harsh or polluted environments. Prior to this work, the affects of anthropogenic disturbance on biotic characteristics of spring systems were poorly realized beyond affects causing population extirpations and extinction (see Miller 1961, Minckley and Deacon 1968, Williams et al. 1985, Sada and Vinyard 2002).

Using this information, it is possible to prioritize springs according to their resource values and restoration needs using matrix analyses to rank biotic and abiotic elements of each spring within a region. Potential analytical elements that may be used in these matrices are shown and described in Tables 5 and 6. Resource agencies may identify other elements that may more appropriately address their management and restoration programs. Priority values derived from these analyses should not be considered to be definitive guidance for management and restoration, but they do indicate the relative importance of each spring and how each one can be considered during management and restoration programs.

Matrix I (Table 5) ranks elements that characterize the relative importance of each spring's resources to resource values for other springs in the surrounding area. These elements include rare species, factors indicating taxonomic richness, the rarity of spring habitats across the landscape, land ownership, and the potential of conflicting uses that may affect biotic integrity. Higher priority springs have higher matrix and resource values, and include larger springs (that generally do not dry during droughts), springs supporting covered species and high species richness, springs in public ownership where management activities can be conducted, and springs where uses do not affect biotic integrity. Lower priority springs have lower matrix values and do not support covered species, have lower taxonomic richness, periodically dry, occur in private lands, and are affected by overwhelming uses that degrade their biotic integrity.

Matrix II (Table 6) ranks restoration priorities by considering habitat condition in addition to the elements used in Matrix I. For this analysis, higher restoration priority is indicated by higher matrix values, which are given to springs with higher resource values and where restoration programs can achieve more rapid and effective success. Therefore, moderately disturbed springs with high resource values are given higher restoration priority than minimally disturbed springs with high resource values and highly degraded springs with low resource value. Lower priority is assigned to the springs with lower resource values and higher disturbance where restoration may have minimal influence on riparian and aquatic communities.

Table 5. Elements and ranking values for Matrix I to rank the relative value of resources at springs. Each spring is ranked by evaluating each matrix element and summing the ranking values for all elements. Elements are described below.

Matrix I Criteria	Ranking Value
Presence of Rare Aquatic Species [1]	Present = 10, Absent = 0
Rarity Across Landscape [2]	Rare = 10, Sparse = 5, Common = 2
Spring Brook Length [3]	> 500 m = 10, ≤ 500 > 200 = 7, ≤ 200 ≥ 50 = 5, < 50 = 2
Scouring [4]	None = 10, Occasional = 5, Frequent = 2
Aquatic Habitat Persistence [5]	Persistent = 10, Ephemeral = 2
Resource Threats [6]	High = 2, Medium = 10, Low = 7
Land Ownership [7]	Public = 10, Private = 3
Conflicting Uses [8]	≤ 1 = 10, 2-3 = 5, >3 = 2

[1] Springs with rare plants or crenobiontic species are ranked 10, springs without rare species are ranked 0.

[2] Spring rarity is a subjective scale of density across the landscape. In southern Nevada, density is comparatively high in spring provinces, moderate along the much of the east side of the Spring Mountains, and scarce in areas such as the west side of the Spring Mountain, in the McCullogh Range and Muddy Mountains.

[3] Length is the distance in meters of the spring brook from the source to the end of contiguous flowing surface water.

[4] Scouring is based on the potential of scouring due to flooding. Frequent scouring may have a lower resource value and recovery potential.

[5] Persistence is the long-term presence of surface water. It is indicated by riparian systems with obligate wetland species and macroinvertebrate communities that are dominated by water boatman (corixids), diving beetles, and other highly vagile, invasive species. If spring snails are present, then there is persistence. Springs that dry have low recovery potential as aquatic habitats, but they may be important to amphibians.

[6] Threats is a subjective evaluation of the likelihood that current activities will further degrade spring resource quality or keep it in a degraded condition. High threats usually mean a spring will be more difficult to restore. Low threats means land managers will likely want to keep the spring in its existing condition.

[7] Ownership is either private, State, or Federal.

[8] Conflicting Uses is a subjective ranking of how current uses conflict with management objectives. There can be three types of conflicting uses: (1) introduced grazing, (2) diversions, (3) recreation. If none of these are present the ranking is 0. If one of these conflicting uses is present the ranking is 7. If two conflicting uses are present the ranking is 5, and if three are present the ranking is 2.

Table 6. Elements and ranking values for Matrix II to rank the restoration priority of springs. Each spring is ranked by evaluating each matrix element and summing the ranking values for all elements. Elements are as described for Matrix I, and below for elements used in only Matrix II.

Matrix II Criteria	Analysis Scale
Presence of Rare Aquatic Species [1]	Present = 10, Absent = 0
Rarity Across Landscape [2]	Rare = 10, Sparse = 5, Common = 2
Spring Brook Length [3]	> 500 m = 10, ≤ 500 > 200 = 7, ≤ 200 ≥ 50 = 5, < 50 = 2
Scouring [4]	None = 10, Occasional = 5, Frequent = 2
Aquatic Habitat Persistence [5]	Persistent = 10, Ephemeral = 2
Resource Threats [6]	High = 2, Medium = 10, Low = 7
Land Ownership [7]	Public = 10, Private = 3
Conflicting Uses [8]	≤ 1 = 10, 2-3 = 5, >3 = 2
Habitat Condition [9]	Slight/Unmodified = 5, Moderate = 10, High = 2
Recoverability [10]	High = 10, Medium = 5, Low = 2

[9] Habitat condition ratings are described in Level I protocol guidelines. Moderately disturbed springs receive higher ranking because restoration activities are more necessary than at slightly an undisturbed springs. Highly disturbed springs receive lower ranking because many of them are so badly disturbed that restoration is a very long-term process that requires substantial resources.

[10] Recoverability includes the physical and biological aspects necessary to recover a spring. It does not include cost, feasibility, staffing needs, or political considerations.

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Appendix A – Glossary

Abiotic – non-living, factors of the environment including light, temperature, and atmospheric gases; physical and chemical characteristics of a site.

Abundance – the number of individuals, such as 100 spring snails.

Alkaline–soil or water with high concentrations of mineral salts; strongest concentrations can be caustic.

Allochothonous – originating from another place, as opposed to originating in place.

Anthropogenic –caused by human activities.

Aquifer – an underground layer of rock, sand, etc. containing water.

Autochthonous – originating in place, as opposed to being brought in from another place.

Autotrophic – making its own food by photosynthesis (green plants) or chemosynthesis (some bacteria).

Bosque – a grove of trees; woodland.

Cohorts – associated plants, animals, etc.

Crenobiont –species that dwell only in springs.

Edaphic – pertaining to the physical and chemical characteristics of soil.

Endemic – native to a particular geographical area as a county, state, region.

Ephemeral – short-lived, transitory.

Extant – still existing, not extinct.

Extinct – no longer in existence; having no living descendant.

Extirpate – to completely remove or destroy.

Facultative – capable of living under varying conditions.

Fault zone – a fracture or zone of fractures in rock strata.

Feral – untamed, wild.

Frugivorous – fruit-eating

Granivorous – seed-eating

Helocrene – a spring originating from a marsh or bog

Indigenous – native to a particular geographical area

Insectivorous – insect-eating

Limnocrene –a spring originating from a large, deep pool of water

Lotic –living in flowing water, as in a river or stream

Macroinvertebrate – insects, snails, clams and other animals without backbones that can be seen without magnification

Mesic – moderately moist, as in between very dry (xeric) and wet (hydric)

Morphology – the form and structure of plants, animals, landforms

Obligatory – limited to specific conditions of temperature, moisture, habitats, etc.

Orifice –opening of a tube, cavity, etc.

Osmoregulation – control of flow of fluids through a membrane

Perturbations – disturbances

pH – the measure of acidity/alkalinity

Phreatophytes – deep-rooted plants that absorbs water from the water table or groundwater layers, like tamarisk

Pluvial – pertaining to 1) substrates, landforms, etc. formed as a result of rain or ephemeral streams, 2) climatology: relating to former periods of abundant rains

ppm – parts per million

Qualitative – identifying the different elements or components of a mixture; such as the different kinds of species in a habitat

Quantitative – finding the amounts of components; determining the relative amounts of a mixture; such as the relative numbers of different species in a habitat, etc.

Relict – a plant, animal, or habitat surviving as a remnant and persisting in isolation from earlier populations and time

Rheocrene – a spring that flows from a defined opening into a confined channel

Richness – the number of different species of an area

Riparian – associated with the edges of a spring, stream, lake, or river, such as a riparian species, landowner, etc.

Scouring – erosion by moving water; where flowing water moves and/or removes silt, mud, gravel, stones

Seep – a place where water oozes from the ground or rock through small openings

Spatial – the distribution of organisms, springs, etc. over an area

Spring – a place where water naturally flows from the ground or rock upon the land to form a stream or into a body of water

Temporal – time

Terrestrial – living on the land, as different from living in water

Vagile - animals that can disperse over long distances by flying, walking, or swimming

Xeric – dry or desert-like conditions

Appendix B – Field Form

FIELD NOTE NO. _____ SURVEYOR(S) _____ DATE _____

STATE_____ COUNTY_____

LOCALITY_____

DRAINAGE_____ T _____ R_____ ¼ SEC_____

1:100,000 USGS QUAD _____

1:24,000 USGS QUAD _____

GPS ZONE: ____ NORTHING _____ EASTING _____

PDOP: _____ LATITUDE _____ LONGITUDE _____

VEHICLE ACCESS: +/- PHOTO +/- ELEVATION:_____

OWNER: USFS BLM TRIBAL MILITARY PRIVATE

Other_____

SPRING TYPE: HELOCRENE RHEOCRENE LIMNOCRENE DRY OTHER

DISCHARGE:_____ SPRNGBROOK LENGTH:_____

WATER DEPTH:_____ WATER WIDTH:_____ DO:_____

TEMPERATURE: _____ CONDUCTIVITY: _____ pH: _____

VEGETATIVE COVER (%): emergent_____ bank_____ watercress _____

SPRINGSNAIL SPECIES: _____

scarce common abundant

FISH SPECIES:_____

AMPHIBIAN SPECIES: _____ AMPHIPODS: + / -

CLAMS: + / - NON-NATIVE SPECIES:_____

Other _____

BANK INCISION: + / - BANK STABILITY: poor medium good

SUBSTRATE (%): silt_____ sand _____ gravel _____ cobble _____

boulder _____ bedrock _____

SITE CONDITION: undisturbed slight moderate high

DISTURBANCE: livestock recreation diversion residence

other _____

NOTES: _____