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

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INTRODUCTION

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 for wildlife has also become increasingly apparent (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 plants are endemic to western U.S. springs, which shows that they are also important to a wide variety of rare plants and animals (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 discharge rates, aquifer sources, and the presence of rare species (e.g., fishes, aquatic macroinvertebrates, rare plants, etc.) have been assessed at some springs, basic information describing physical and biological characteristics of arid land springs is very limited. This paucity of knowledge has often resulted in permitting activities that adversely affect spring aquatic and riparian biota (Shepard 1993). Management is challenged to respond to these issues because many uses and management activities have adversely affected biodiversity and resulted in status declines of rare species (Sada and Vinyard 2002). At this time, assessing the efficacy of management is often difficult because springs are unique systems, spring survey and monitoring methods are largely unknown, and spring resources are often unknown to most resource managers.

The U.S. National Park Service, Mojave Inventory and Monitoring Network (Mojave I&M Network), is responding to these deficiencies by working with the Desert Managers Group to prepare a series of inventory and monitoring protocols that are specific to spring systems within their jurisdictions. These protocols are consistent with a planning process that accumulates information at several different quantitative levels and reviews issues at differing scales of resource challenge. They also provide a broad base of information that can be compiled by all public and private agencies to characterize springs and monitor for long-term changes in their biota and physicochemical environment. Using consistent data collection methods will allow cooperating agencies to compile and disseminate information and facilitate assessments of spring resources across a broad geographic area.

Gathering information for this spring inventory and monitoring program is accomplished by data mining and two hierarchical field surveys. A database is then created to archive information. Data mining is conducted to compile information from agency files that document historical work on springs in a management area. This may include wildlife surveys, water chemistry data, etc. This is followed by Level I field studies that inventory all springs or water features (the types of water sources included in these surveys may vary with resource needs within a management area) by visiting all water sources within a defined geographic area (e.g., within a national park). This inventory records the spring location, and characteristics of the spring that include its size and morphology, basic water chemistry, the presence of important plants and animals, and natural and anthropogenic factors stressing the aquatic and riparian systems. This information can be used to generally assess the biotic integrity of springs and conditions resulting from existing management practices. If conditions do not meet existing management goals and guidelines, Level I surveys should be followed by Level II surveys, which quantify temporal variation in aquatic and riparian communities, characteristics of the aquatic habitat, and water chemistry to document how the spring system changes over time. This level of investigation provides more rigorous insight into the environmental and biotic responses to changes in management. A third level of surveys may also be conducted to more accurately quantify spatial and temporal variability in water chemistry and aquatic and riparian habitats and communities. This information may also quantify the age of water, relatively precise assessment of water age and sources, seasonal and annual variability in biotic and physiochemical factors, and specific microhabitats that are required by aquatic and riparian species,. This level of work is included in these protocols. In summary, the four elements to the hierarchical assessment of springs through Level I and Level II are:

1. Data mining to review existing information, protocols, and databases related to inventory of spring-fed water features within a designated management area.
2. Level I surveys to inventory isolated water features that include 1) natural springs and seeps (groundwater that flows onto the land surface through natural processes), 2) hand and mechanically dug wells (groundwater that flows onto the land surface because of vertically oriented human excavation), and 3) artificial surface water expressions or qanats, and water

troughs (groundwater that flows onto the land surface because of horizontally oriented human excavation). The purpose of Level I surveys is to characterize salient aspects of each spring's aquatic and riparian environments. These surveys are reconnaissance-level observations that focus on locating springs and generally assessing biotic potential that can be used to facilitate management and prioritize the importance of individual springs within the park ecosystem. This information is neither highly detailed nor accumulated in a rigorous manner that allows statistical analysis. It is a tool that characterizes spring resources and provides information that can be used to assess management needs and prioritize spring resources. Collection of highly quantified data requires much more detail, time, and substantially greater funding than is necessary for Level I surveys.

3. Level II surveys that are the basis of a long-term monitoring program that quantifies temporal variation in biotic and physicochemical characteristics of individual springs. These surveys should be conducted annually for three to five years to determine baseline conditions. Sampling frequency may be reduced to every three to five years once baseline conditions are accurately quantified. The number of springs, duration of surveys, and goals and purposes of Level II surveys should be developed by a team of managers, ecologists, and hydrologists. These surveys include water chemistry analyses, quantitative description of aquatic habitats, and the identification and enumeration of riparian and aquatic taxa to species or genus, respectively. Information provided by these surveys will 1) quantify baseline conditions at the beginning of a monitoring program and 2) quantify changes in biotic and abiotic characteristics of springs under existing or newly implemented management strategies. Level II surveys may include only springs where the effects of altered management strategies should be documented, and they may be implemented to determine landscape changes in biotic and abiotic condition of springs.
4. Compilation of survey and monitoring information into a Microsoft Access® database.

The foundation for these protocols is provided by a number of hydrological and biological studies of springs in the western U.S. and elsewhere (e.g., Ferrington 1995, Botosaneau 1998, Meffe and Marsh 1983, Williams and Danks 1991, Thomas et al. 1996, Sada et al. 2005, and many other references that are cited herein) that have examined spring physicochemical conditions and their influence on aquatic and riparian systems.

This document includes a number of sections that educate surveyors about physicochemical and biological characteristics of springs, describes collection methods for Level I and Level II surveys, defines terms used in the protocols (Appendix I), recommends field forms, describes how to identify important animals, and provides an example of how information from Level I surveys can be used to prioritize management and restoration activities. Guidelines are also provided to prevent translocating animals among springs while conducting surveys. These protocols include minimum information that should be compiled at each spring for Level I and Level II surveys. Individual agencies or jurisdictions may wish to include other variables to customize these assessments for specific management needs.

WHAT ARE 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 (Meizner 1923, Hynes 1970). They are distinct from other aquatic systems because 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 many support obligatory, spring-dwelling species (crenobiontic species) (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 subterranean 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 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, and water chemistry is strongly influenced by aquifer geology. Perched, local, and regional aquifers are the basic types of aquifers in the western U.S. These aquifers differ primarily in their transmissivity, and hence their water chemistry and persistence. In general, water in highly transmissive aquifers (e.g., perched aquifers) contains fewer dissolved chemical constituents than water in aquifers with low transmissivity (e.g., regional aquifers).

Perched Aquifers

In the western U.S., springs at high elevations (> 1,800 m [~6,000 ft]) and on mountain blocks are generally supplied by perched aquifers. These aquifers are small and fed by precipitation covering a small area (e.g., a drainage basin, small portion of a mountain range, or series of hills). Perched springs are cool (<10°C), usually small, and often dry during periods of low precipitation. Seasonal and annual variability in discharge may also be large.

Local Aquifers

Local aquifers are fed by precipitation from a larger area (e.g., a mountain range) and springs they support are located between valley floors and the base of mountains. Flow through these aquifers is generally deeper (< 500 m) and springs are usually cool, but warmer than perched aquifer springs (< 20°C). Geothermal springs (> 40°C) are also supported by local aquifers that circulate near magma that heats water to temperatures that dissolve rocks to increase the concentration and number of chemicals. Discharge from springs fed by these aquifers may also change seasonally and annually in response to precipitation, but most of these springs dry only during extended droughts.

Regional Aquifers

Springs fed by regional aquifers are warm (>20°C) and supplied from recharge extending over vast areas. Flow through these aquifers is complex, controlled by fractures, and may extend beneath valleys and topographic divides (Mifflin 1968, Winograd and Thordarson 1975, Thomas et al. 1996). The movement of water through these aquifers is slow compared to perched and local aquifers. Water in regional aquifer springs may also contain elevated chemical concentrations and TDS level because the long residence of time and elevated temperatures facilitate the dissolving of rock and minerals. In contrast to springs supported by perched and local aquifers, discharge from regional springs is constant over long periods of time (often >1,000 years, and exceeding 50,000 years; Winograd et al. 1992).

Physical and Chemical Characteristics of Springs

Springs and seeps occur in many sizes and shapes, and the complex influences of aquifer geology, morphology, discharge rates, and regional precipitation and vegetation dictate that environmental characteristics of most springs are unique (see Hynes 1970, Garside and Schilling

1979). They can be cold (near or below mean-annual air temperature), thermal (>5°C and <10 °C above mean-annual air temperature [van Everdingen 1991]), or hot (water temperature >10°C above mean-annual air temperature [Peterken 1957]). They 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 milligrams/liter [mg/l]) in hot springs, and high (> 5 mg/l) 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 microsiemens/centimeter/second [μmhos]) in springs supported by perched aquifers 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.

Spring size is generally a function of its discharge. Seeps are small springs that support vegetation that is adapted to drier conditions (e.g., upland and facultative wetland species), and seeps that are dry on a regular basis. Springs may also be small but they support larger aquatic habitats, dry less frequently, and they are generally surrounded by more robust riparian zones with species that rely on moist soils (e.g., obligatory and facultative wetland species). Springs may be broadly categorized by the morphology of their source. *Limnocrenes* are springs with water flowing from a deep pool, *helocrenes* are marshy and bog-like, and *rheocrenes* have a well-defined source that flows directly into a confined channel.

Springs occur singly and in provinces that include many sizes and morphologies. Most springs below approximately 2,100 m (7,000 ft) in western North America are isolated and flow a short distance before drying (Deacon and Minckley 1974). Many springs in this region also dry periodically, while few flow into rivers, lakes, or streams, and spring provinces may support extensive wetlands.

Biological Characteristics of Springs

Physical and chemical features are dominant factors influencing spring-fed riparian and aquatic plant and animal communities (van der Kamp 1995, Sada et al. 2005). Plant and animal assemblages in springs may be similar to aquatic and riparian assemblages associated with regional streams and ponds (with the exception of crenobiontics). However, arid land spring communities exhibit unique compositional and structural characteristics that are attributed to their distinctive environments and to colonization/extirpation dynamics that characterize small, isolated habitats. Riparian and aquatic communities at hot springs are distinct from other spring systems and from all other biotic systems in the western U.S. (Milligan et al. 1966, Garside and Schilling 1979).

Although abiotic and biotic characteristics of most arid land springs are distinctive, a number of general factors are known about ecological relationships. Riparian vegetation at cool water springs and springs with lower thermal temperatures is generally comprised of species associated with regional streams, lakes, and marshes (e.g., willows, mesquites, sedges, and grasses). This vegetation may be dense at springs that are minimally disturbed, but springs that are disturbed by natural (e.g., scouring floods, fire, avalanche) and cultural activities usually have less diverse riparian communities that include more non-native and upland species (Fleishman et al. in press). Riparian vegetation may be restricted to the immediate boundaries of a spring's aquatic habitat, or it may extend outward for substantial distances where water seeps outward from aquatic habitats and moistens hydric soils (e.g., in spring provinces). The structure of riparian communities varies considerably with many factors, including discharge, spring elevation, soil type, and disturbance levels. Vegetation associated with thermal springs is usually tolerant of soils with elevated salinity and alkalinity (Kristijansson and Hreggvidsson 1995). Vegetation at larger and minimally disturbed springs is dominated by sedges, rushes, grasses, and woody phreatophytes (e.g., willows at middle to higher elevations, mesquite at lower elevations). Vegetation at seeps is typically limited to grasses and rushes.

Smaller springs are generally autotrophic aquatic systems with little dependence on allochothonous carbon sources (Minshall 1978, Cushing and Wolf 1984). In larger springs, energy may enter the system during periodic floods that flush carbon from the surrounding landscape. As a consequence, most spring environments are less variable than other aquatic habitats (e.g., streams, rivers, and lakes), which causes 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 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 is usually different, and many species that occupy the source are frequently absent from downstream habitats (Hayford et al. 1995, Hershler 1998, O'Brien and Blinn 1999). Many taxa occupying source habitats do not occur downstream where temporal fluctuations in water temperature and flow are greater and may exceed the physiological tolerance of source-dwelling species (Erman and Erman 1990, Erman 1992). 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 that highest density was near the source and during the period January through September.

A number of studies have also observed that abundance 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). Aquatic life is also influenced by morphology. Species that inhabit rheocrenes prefer flowing water and species in limnocrenes and helocrenes are better adapted to lentic environments (Sada et al. 2000).

Crenobiontics appear to be specifically adapted to their home environment. Although additional information is needed to identify habitats preferred by most crenobiontics, it appears that they are most abundant within 50 m of a spring source, and scarce or absent from the downstream-most reaches of spring brook. It also appears that each species also prefers a specific microhabitat. 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). Sada and Herbst (1999) found that habitat partitioning among three springsnail species (*Pyrgulopsis avernalis*, *Pyrgulopsis carinifera*, and *Tryonia clathrata*) was based on water depth, current velocity, and substrate composition. O'Brien and Blinn (1999) showed that *P. montezumensis* preferred specific levels of CO_2 that were restricted to a short portion of spring brook. Endemic beetles (e.g., *Stenelmis* sp. and *Microcylleopus* sp.) and true bugs (e.g., *Ambrysus* sp. and *Limnocoris* sp.) are most common where gravel substrate occurs with high current velocities (Sada and Herbst 1999). The Devil's Hole pupfish (*Cyprinodon diabolis*) also selects specific habitat for spawning (Deacon and Deacon 1979).

Because of the relative isolation of many arid land springs, plant diversity and endemism are frequently higher than communities in other aquatic systems and 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 to 150 species) was also recorded at springs along the southwestern edge of the Great Basin in Owens

Valley, California (DeDecker 1980, Ferren and Davis 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 showing 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 that they are important habitats 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 establish nesting areas and displace native species (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 the American Robin (*Turdus migratorius*), Townsends Solitare (*Myadestes townsendi*), Mountain Bluebird (*Sailia currocoides*), Northern

Flicker (*Colaptes cafer*), 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 Steller's 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.

Many species of bats also use water and insects at springs (O'Farrell and Bradley 1970, 1977).

<u>Rare and Other Important Species</u>

A number of important species are associated with springs. These include rare species that may require specific management and introduced species that may adversely affect biotic integrity.

Taxonomic studies over the past 120 years have found a large number of endemic plants, vertebrates, and macroinvertebrates associated with arid land springs throughout western North America (see Miller 1958; Taylor 1966, 1985; Minckley 1977; Skinner 1994; Hershler 1998; Schmude 1999). 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 crenobiontic fauna is now known from 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 do not 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).

While there have been few descriptions of new fish taxa in the western U.S. within the past

20 years, more than 100 species of spring-dwelling aquatic mollusks, crustaceans, and insects have been recently described from smaller springs that are not occupied by native fishes (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). 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 was formalized in a Memorandum of Understanding for Great Basin springsnail conservation, which was signed by The Nature Conservancy, Smithsonian Institution, U.S. Department of Interior (U.S. Fish and Wildlife Service, U.S. Bureau of Land Management, U.S. National Park Service, and U.S. Geological Survey), and U.S. Forest Service during 1998. 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 and their distributions are well understood. These surveys have included most large spring habitats and streams, and opportunities for finding new populations are comparatively small. Macroinvertebrate surveys have been uncommon, 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 populations and new species will be discovered during future surveys. The paucity of information about these species suggests that future spring surveys will provide substantial new information about their distribution, biogeography, and status. Table 1 shows taxonomic groups of native crenobiontic macroinvertebrates that are most likely to be found during spring surveys in the western U.S. (see Myers and Resh 1999; Hershler 1998, 1999; Schmude 1999, Polhemus and Polhemus 2002). Many of these animals are illustrated in Appendix IV.

Spring-fed riparian habitats are also used by vertebrates that 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.

Table 1. Taxonomic groups of crenobiontic aquatic macroinvertebrates that most commonly occur in western North America springs.

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

Table 2. Common non-native species known from arid land springs.

Fishes
Mosquito fish (*Gambusia affinis*)
Guppy (*Poecillia reticulata*
Goldfish (*Carassius auratus*)
Mollies (*Poecilia* spp., *Xiphophorus* spp.)
Cichlids (Family Cichlidae)
Large mouth bass (*Micropeterus salmoides*)
Amphibians
Bullfrog (*Rana catesbeiana*)
Mollusks
Red-rimmed melania (*Melanoides tuberbulata*)
New Zealand mudsnail (*Potamopyrgus antipodarum*)
Crustaceans
Order Decapoda (crayfish)
Vegetation
Salt cedar (*Tamarisk* sp.)
Palm tree (Family Arecaceae)
White top (*Cardaria pubescens*)
Arundo (*Arundo donax*)
Rabbit's foot grass (*Polypogon monspeliensis*)
Russian knapweed (*Acroptilon repens*)

Non-Native Species

A number of non-native species of animals and plants also occur at springs. Fishes occur mostly in larger habitats, while macroinvertebrates occupy a wide variety of spring sizes and types. Although non-native vegetation occurs primarily at disturbed sites, these species also occur over broad areas. The most common non-native plant and animal species that are associated with arid land springs are shown in Table 2. Refer to Bossard et al. (2000) and Whiston et al. (1992) to identify these plants. Common non-native animals found in springs are illustrated in Appendix IV.

Important Stress Factors Structuring Biotic Communities

Stresses attributed to environmental harshness and anthropogenic disturbance overlay and supplement hydrologic factors that influence spring ecosystems. These factors may act singly or simultaneously and the aquatic and riparian communities are usually structured by the factor that causes the greatest stress. As in other systems, the ecological effects of these factors are a function of their frequency, duration, and severity. Spring systems are relatively unaffected and they will recover quickly from infrequent and slight stresses, and they typically support species that are intolerant of harsh conditions. In contrast, severely stressed systems are occupied by tolerant species and recovery to pre-stress conditions will occur over a long time. Natural stress factors include disturbances from periodic drying, fire, avalanche, scouring floods, and trampling by native ungulates (e.g., elk), and aquifers that provide high water temperatures and chemical concentrations. A number of anthropogenic stress factors also disturb springs. These include diversion (ground water pumping, spring box capture and piping to troughs, channelization, etc.), impoundment, nutrient pollution, introduction of non-native plants and animals, and trampling by humans and non-native ungulates (Shepard 1993, Minckley and Unmack 2000, Sada 2001, Sada and Vinyard 2002). In a survey of 505 springs throughout northern Nevada, Sada et al. (1992) found greater than 85 percent of springs were moderately or highly disturbed by livestock and diversion. Less than five percent of springs were unaffected by human disturbances.

Highly stressed springs (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 in these environments is adapted to conditions where osmoregulation and respiration are difficult (Brock 1994, McCabe 1998). Flies (Diptera) are the most common animals in harsh environments and bluegreen algae (Cyanobacteria) frequently dominate the periphyton community of hot springs. In cooler habitats where conditions are moderate, stoneflies (Plecoptera), mayflies (Ephemeroptera), and caddisflies (Trichoptera) are common, and communities are most structured by other physical and chemical factors such as spring size and environmental heterogeneity. In montane Sierra Nevada springs, Erman and Erman (1995) found aquatic macroinvertebrate diversity was correlated with spring permanence, calcium concentration, specific conductance, pH, magnesium, and alkalinity. Aquatic communities in permanent springs generally include more species and more individuals than communities in ephemeral springs and seeps (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 colonizing intermittent habitats. Sada et al. (2005) and Fleishman et al. (in press) found that spring size and condition influenced spring biodiversity.

Sada et al. (2005) and Fleishman et al. (in press) also qualitatively assessed stress levels in relation to functional characteristics of aquatic and riparian communities at springs. They observed biotic characteristics varying along a gradient of disturbance. As stress increased, the richness in aquatic and riparian communities declined, the abundance of tolerant macroinvertebrates increased. Obligatory and facultative wetland vegetation declined and was replaced by upland species. There were also similarities between their response to natural and human-induced stresses. Drying by diversion (groundwater pumping, spring box capture, etc.) and natural drought both eliminated aquatic communities and increase upland species in the riparian zone. Scouring by flood and trampling by humans, elk, and livestock all eliminate riparian vegetation and create autotrophic conditions where highly tolerant aquatic species dominate communities. These similarities show that identifying and estimating the magnitude of stress factors is critical to defining ecological status and potential, and management goals. Aquatic and riparian communities at springs that were stressed by only anthropogenic factors differ substantially from those that are unaffected by these activities. The biotic integrity of these disturbed springs is also diminished. Changes in management can ameliorate these stresses and allow biotic integrity to be restored. This is in contrast with springs that are stressed by natural factors because their biotic integrity is comparatively unaffected by management or anthropogenic stresses.

Natural Stress Factors

Springs occur across all landforms, elevations, and aspects of the western U.S. landscape. Springs in areas with greater, and less variable, precipitation and on valley floors are usually less disturbed by natural factors than springs in drier regions and gullies and springs affected by stochastic weather events. Some of the most common natural factors that stress springs are:

- Scouring. Springs that are most susceptible to scour occur in the bottom of gullies where they are exposed to high flows during spring runoff or thundershowers. Aquatic and riparian communities that are located in gullies range from being depauperate where scouring is frequent to relatively rich where scouring is infrequent, short-termed, or minor. Springs located on the sides of gullies and washes may be unaffected by scouring, but these events may have a strong influence on their spring brook communities that are located in the gully bottom.
- Drought. Some springs are more susceptible to drying during drought than others. Compared to persistent springs, riparian communities at springs that dry include more upland and drought-tolerant species, and aquatic communities include vagile, tolerant species that rapidly colonize ephemeral systems. At springs that dry, both of these communities are depauperate in comparison with persistent springs.
- Water Chemistry. Harsh chemical conditions occur in hot springs (temperature > 20°C above mean annual air temperature) and springs supported by aquifers carrying high mineral concentrations. Under these types of conditions, physiological and osmoregulatory pathways of most aquatic life breaks down and survival is not possible. Harsh water chemistry also influences the chemical composition of riparian soil, which may create harsh conditions that are poorly tolerated by many riparian plant species. Springs with harsh water chemistry have fewer species, and species that are tolerant of harsh conditions, than springs with benign water chemistry. High temperature springs are usually supported by local aquifers where groundwater is buoyed upward by hot magma that is near the surface.
- Fire. Fires are common across the western U.S., and many springs are burned frequently. Fires affect springs in a manner that is similar to their affect on lotic systems. Fires often remove large quantities of riparian vegetation and stress aquatic systems by elevating water temperature, increasing siltation, and altering pH levels through the introduction of ashes.

Spring systems recover from fire through a series of successional stages where invasive and tolerant species comprise early communities. These communities are replaced by woody vegetation and less tolerant species over time. These changes occur over a long period, and they may be interrupted if fires are frequent. Springs that are frequently affected by fires will support many invasive plant species, little woody vegetation, and depauperate aquatic communities that consist mostly of tolerant macroinvertebrates.

- Avalanche. Avalanches affect only mountain springs that are on the floor of gullies at high elevations. Springs in avalanche paths are disturbed during winter and support willow or moss vegetation. Larger woody vegetation (e.g., aspen) is absent. Where water is persistent, macroinvertebrate communities may be comparatively diverse because water is cold, high quality, and the aquatic habitat is comparatively heterogeneous due to larger substrates and substantial quantities of interstitial space. Springs in avalanche paths that dry are influenced more by this factor than by stress from avalanches.

Anthropogenic Stress Factors

Human activities have altered the physical and biological condition of most springs in western North America (Shepard 1993). Early changes were made by native peoples and settlers, who often relied on springs as water sources. It appears that activities of native peoples minimally affected springs in most areas because they lacked equipment necessary to dredge, store, or transport large quantities of water. While some arid land springs were altered by native people for agriculture (e.g., Mehringer and Warren 1976, Fowler and Fowler 1990), these activities appear to be focused on streams along the Wasatch and Sierra Nevada ranges and larger spring systems (e.g., Steward 1933, Madsen 1989). The activities of native peoples probably affected more springs in drier portions of the intermountain region (e.g., Mojave Desert) where they improved access to water by excavating shallow wells to pool water in a qanat. These springs now appear to be highly disturbed, and they are more accurately classified as wells, but these 'springs' are often the only water over large areas and it is difficult to determine which qanats were developed from persistent springs and which were intermittent seeps with occasional surface flow.

Settlers developed springs for homes and livestock by dredging, impounding, and often piping water to distant locations. As the population of settlers increased, changes in spring condition followed, including introductions of non-native plants and animals, and more extensive alterations that channelized spring brooks, and dried springs by diversion and excessive groundwater withdrawal. These activities affected spring biota by decreasing habitat size (both incrementally and completely) and vegetative cover, and changing aquatic and riparian community composition. This caused the loss of native species through habitat alteration, and competition and predation (see Miller 1961, Dudley and Larson 1976, Miller et al. 1989, Hershler 1998, Sada and Vinyard 2002). Changes in riparian vegetation composition and density also altered aquatic system energy budgets (changing the aquatic system from allochthonous to autochthonous) and reduced larval food and reproductive habitats for terrestrial phases of aquatic insects. These changes probably decreased food availability for many bird species (Erman 1984, 1987). These activities continue, and springs that have not been altered by these activities are few (Sada et al. 1992). The most common anthropogenic activities affecting springs are:

- Trampling. Most arid land springs have altered by livestock, and wild horse and burro grazing and trampling. Sada (2001) documented how trampling by recreationists affected the abundance and distribution of spring-dwelling mollusks in Death Valley, California. The impact on springs is similar to those caused by excessive grazing in riparian and aquatic systems where it has degraded riparian vegetation, and increased water temperature, the amount of fine substrates, and nutrient loading (Kauffman and Krueger 1984, Fleischner 1994).
- Diversion. Springs diversions include spring brook channelization and redirection, delivering water through pipes and concrete channels to tanks and reservoirs, excavating and installing spring boxes, impounding spring sources, and decreasing discharge from excessive groundwater pumping. Diversions that remove very small amounts of water may minimally affect spring biota. Activities that occur infrequently and involve small disturbances may also minimally affect biota if sufficient time passes for the spring to naturalize after each disturbance (it may take decades for a spring to naturalize after these types of disturbances). Effects of diversion are similar to the consequences of drought that dry springs or greatly reduce discharge. In general, species richness declines as diversion increases, and there are functional shifts in the structure of aquatic and riparian communities. As diversion increases, intolerant aquatic species (e.g., mayflies, caddisflies,

crenobiontics) are replaced by tolerant taxa (e.g., midges, beetles, corixids, etc.) and non-native and upland vegetation become dominant members of the riparian community.

- Non-Native Species. Many non-native plant species are detrimental to spring systems,and many of these are classified as noxious weeds. These species pose a significant impact to the ecological function of spring systems by reducing overall plant and animal diversity and by altering site hydrology. Salt cedar (*Tamarix* spp.), purple loostrife (*Lythrum salicaria*), Canada thistle (*Cirsium arvense*), knapweeds (*Centaurea* spp.), and perennial pepperweed (*Lepidium latifolium*) are the most common non-native plants affecting western wetlands. Seed germination and dissemination, and physiological characteristics of these species make them competitively superior to native vegetation, and adept at displacing native vegetation at sites that have been disturbed by water impoundments, excessive grazing and recreation. By displacing native vegetation they reduce habitat that formerly provided critical nesting, feeding and spawning habitat for wildlife species.

  A number of non-native vertebrates and invertebrates have also been introduced into springs in western North America. Mosquito fish (*Gambusia affinis*) is probably the most widely introduced vertebrate because it has been used as a biological control agent for mosquitoes throughout the world (Courtenay et al. 1984). Many species of aquarium fish have been introduced, primarily into thermal springs (e.g., goldfish, *Carassius auratus*; sailfin molly, *Poecilia latipinna;* shortfin molly, *Poecilia mexicana*). Bullfrogs (*Rana catesbeiana)* have also been widely introduced for sport. A number of self-sustaining populations of sport species of fish (e.g., rainbow trout, *Onchorynchus mykiss*, and large mouth bass, *Micropterus salmoides*) are also established in springs. Crayfish (usually *Pacifastacus lenusculus*) and red-rimmed melanoides (*Melanoides tuberculata*) (an aquatic snail) are believed to be the most commonly introduced invertebrates in western springs. Populations of aquatic species have either been reduced or extirpated as a result of these and other species being introduced into western spring systems (Schoenherr 1981, Moyle 1984, Taylor et al. 1984, Hershler 1998, Sada and Vinyard 2002).

- Pollution. Springs are susceptible to pollution from a number of activities. Pollutants may be toxic, which may exterminate aquatic and riparian life. They may also increase nutrient concentrations (e.g., nitrogen, phosphorus, etc.) that increase the growth of aquatic vegetation and bacterial abundance and lower dissolved oxygen concentrations. These changes may change intolerant macroinvertebrate communities to communities that characterize polluted aquatic systems (see Rosenberg and Resh 1993). The most common sources of pollution affecting springs are:

- Non-native ungulate activity. Wild horses and burros, cattle, and sheep often congregate around springs. This activity tramples vegetation, which diminishes riparian vegetation and eliminats a buffer that prevents silt and elevated levels of nutrients from entering the aquatic system. Fecal material is often deposited in and around aquatic systems, which elevates nutrients.
- Refuse Disposal. Disposal of solid and liquid waste in landfills and industrial and municipal waste in holding ponds produces pollutants that may leach into the groundwater and move to springs along a hydraulic gradient. Materials that most frequently enter groundwaters are chemicals from mine stockpiles and tailings, landfills, sewage treatment ponds, fertilizers and pesticides, hazardous waste disposal, and accidental spills of hazardous chemicals and waste.
- Groundwater and Injection Wells. Groundwater contamination may occur from material leaking from abandoned or improperly constructed wells. Surface water injected into the ground may enter an aquifer that supports spring discharge, causing pollution. Springs may also be affected by injection of cool water that change thermal characteristics of spring discharge.

SURVEY PROTOCOLS

The hierarchical elements that comprise the Mojave I&M Network spring inventory and monitoring program are described below. First, an office assessment is conducted to compile information about springs within the area to be surveyed (which is usually a defined management unit such as a national park, national forest, etc.). The second survey element (Level I) is a qualitative inventory to locate and characterize springs within a management unit. These surveys describe spring characteristics, spring condition attributed to natural factors and current management practices, and guidance for future management. Level I surveys may be conducted periodically to qualitatively determine temporal changes in biotic and abiotic characteristics of a spring, but Level II surveys should be conducted when quantitative monitoring and assessment