

Environmental and Biological Characteristics of Springs in Lake Mead National Recreation Area, Nevada and Arizona



Blue Point Spring, Lake Mead National Recreation Area

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EXECUTIVE SUMMARY

Ground and surface water dynamics were identified as highest priority management issues during a 2004 Vital Signs Workshop for the Mojave Network of National Parks. In response, the Inventory and Monitoring program initiated surveys to describe physical, chemical, and biological characteristics of springs and identify management needs in each Network park. This report summarizes information gathered in Lake Mead National Recreation Area (LAME) during a 2007 spring inventory. Data collected at each spring are compiled in an Access® database that is maintained at LAME. A total of 89 springs were inventoried. Seventy-two springs were flowing during surveys and most springs were located below 1,000 m elevation. Most springs also discharged less than 25 liters/minute and support spring brooks less than 100 m long. Most LAME springs were relatively harsh environments because of water chemistry, natural drying, and susceptibility. Water temperature ranged from 6°C to 60.7°C and it was greater than 15°C in 40 of 63 springs where measurements could be taken (median = 18.7°C). Electrolyte concentrations (EC) were also high (median = 2,126 microseimens/cm [μmhos]), with EC less than 300 μmhos in only eight springs. High EC values may be attributed to salt in aquifers supplying LAME springs. Approximately 70 percent of springs in the Park were also affected by drying or scouring and approximately 46 percent were impacted by human activity. Five springs were undisturbed by human or natural factors, but EC of each of these springs exceeded 1,000 μmhos . Diversion and recreation were the most frequently observed human disturbances. The presence of non-native salt cedar (*Tamarisk* sp.) was prominent throughout the Park, especially at spring sites and the Lake Mead shoreline. Important aquatic species occurred at 19 springs. Fish were not native, introduced from aquaria, and occurred in only Rogers and Blue Point springs. Woody riparian vegetation was mostly mesquite (*Prosopis* sp.) and salt cedar, with occasional cottonwood (*Populus* sp.) and willow (*Salix* sp.). Cheatgrass (*Bromus* spp.) was the only other non-native vegetation recorded. Obligatory wetland vegetation occurred at less than 20 percent of springs.

Regression analyses were conducted to examine relationships between physical and chemical characteristics (e.g., discharge, temperature, EC, dissolved oxygen, etc.) of LAME springs. Five of 26 relationships that were examined were statistically significant; however, correlation coefficients were low for all regressions, which suggests that these relationships are weak and poorly described by regression equations.

A number of springs are identified for monitoring, management, and restoration. Highest priority monitoring and management springs are Rogers, Bitter, Blue Point, and Grapevine Wash springs. Highest priority restoration sites include these springs in addition to Sauna Cave, and Grapevine Springs in Arizona and Nevada.

The greatest management challenges for LAME springs are restoring degraded habitats, controlling invasive species, and preventing future habitat loss and establishment of non-native species. Restoration programs are needed to ameliorate the effects of human activities that have altered almost one-half of LAME springs and control salt cedar and its affect on spring-fed riparian communities. Non-native aquatic species should also be removed from Blue Point Spring to conserve molluscs that occur only in this spring.

Future challenges for spring management also include preventing introduction of the Quaga mussel (*Dreissena rostriformis bagensis*). This is most likely to occur at Rogers Spring because of recreational bathing and inadvertent transport in footwear, and, like past fish translocation, its concomitant introduction into nearby Blue Point Spring is highly probable. Rapid spread of New Zealand mudsnails (*Potamopyrgus antipodarum*) through the western U.S. suggests that this species may become established in LAME in the near future. Their presence is likely to alter functional characteristics of all LAME aquatic ecosystems and adversely affect spring-dwelling relict leopard frog and mollusk populations. Spring discharge is also vulnerable to effects of groundwater pumping, particularly at springs that are supported by large aquifers that extend beyond LAME boundaries. Monitoring programs are needed to establish baseline conditions of spring environments and biota and to track changes in discharge, physical characteristics of the environment, and their biota. Management programs are needed to ensure that physicochemical changes in the environment and biota do not extirpate populations and alter natural functional characteristics of LAME springs.

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INTRODUCTION

Lake Mead National Recreation Area (LAME) encompasses approximately 607,000 hectares (1,500,000 acres) of southeastern Nevada and northwestern Arizona and portions of the Colorado, Mojave, and Sonoran deserts. Elevation in the park ranges from approximately 275 m (900 ft) in valleys to 1,200 m (4,000 ft) in mountains. Average annual rainfall is approximately 11 cm (4.5 in), and heaviest precipitation occurs during the summer monsoon season. The average summer time high temperature is approximately 46°C (115°F) and annual evaporation ranges from 28 cm (70 in) to 63 cm (160 in).

Lake Mead National Recreation Area encompasses some of the driest landscapes in North America and it is defined by its aridity. Water in the park comes from seasonal runoff, thundershowers, and aquifers that support springs. Runoff and thundershowers often produce scouring flows that quickly pass through ephemeral streams, and springs provide the only persistent, reliable water for humans and wildlife. Springs are also windows into groundwater systems that are supported by local and regional precipitation (Harrill et al. 1988, Thomas et al. 1996). The importance of springs 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, Hershler and Sada 1987, Wiggins and Erman 1987, Hershler and Frest 1996, Hershler 1998, 1999, Schmude 1999, Polhemus and Polhemus 2002, Sada and Vinyard 2002, Smith et al. 2002).

Some LAME springs have been surveyed in the past. Pohlmann et al. (1998) investigated the origin of water for LAME springs. Sada (2000) sampled aquatic macroinvertebrates and environments of several LAME springs and Sada (2002) conducted springsnail surveys throughout Clark County. Hershler (1998, 1999, 2001) described springsnails (*Tryonia porrecta* and *Pyrgulopsis coloradensis*) from Blue Point Spring, and Sada (field notes) recorded the presence of *Assimineia* sp. (a close relative of the Badwater snail [*A. infima*] from Death Valley). *Assimineia* sp. and *P. coloradensis* are endemic to this spring (Hershler 1998, Hershler, pers. comm. July 2008) and *Tryonia porrecta* occurs in many southwest U.S. springs and in Hawaii. In Nevada this includes springs at Moapa, and in the Pahrnatat and White River valleys (Hershler 1999, 2001). Empty (ergo dead) springsnail (*Pyrgulopsis* sp.) shells have also been found at Rogers Springs, suggesting that it supported a historical springsnail population. Springsnails have been extirpated from Rogers Spring and they are very scarce in Blue Point Spring. Relict leopard frogs occupy Rogers, Blue Point, Gnatcatcher, Corral, Boy Scout, Big Horn Sheep, and Salt Cedar springs in LAME (Relict Frog Conservation Team 2005). Past surveys also documented several non-native aquatic species from these springs. The red-rimmed melania (*Melanoides tuberculata*), an invasive non-native mollusk, in Rogers and Blue Point springs, and Rogers Springs is occupied by the soft-shelled turtle (*Apalone spinifera*). Deacon et al. (1964) and Hubbs and Deacon (1964) record the history of aquarium fishes introduced into Rogers Spring, and convict cichlids (*Cichlasoma* [*Archocentrus*] *nigrofasciatum*) and mosquito fish (*Gambusia affinis*) now

occupy both of these springs. Blue Point Spring was fishless until cichlids were introduced during the 1990s (Sada field notes). The proximity of the two springs suggests that fish were established in Blue Point Spring from Rogers Spring.

During a Vital Signs Workshop for the Mojave Network in 2004, groundwater and surface water dynamics were identified as highest priority management issues for Death Valley National Park, Joshua Tree National Park, the Mojave National Preserve, Great Basin National Park, Parashant National Monument, Manzanar National Historic Site, and Lake Mead National Recreation Area. In response to this, the Inventory and Monitoring program initiated a program to inventory and characterize springs in each park and identify management needs. This report summarizes information gathered in LAME during 2007 spring inventories (in the remainder of this document, LAME refers to discussions of all springs within national park boundaries at Lake Mead National Recreation Area). It examines characteristics of park springs but does not discuss information for individual springs. Information regarding individual springs is available by querying the LAME database that contains all of the inventory information. At the request of LAME managers, this summary also includes a matrix analysis that prioritizes springs where monitoring programs can be initiated to track long-term changes in spring environments and ecology. A similar matrix analysis prioritized spring restoration sites.

BACKGROUND

Discharge rates, aquifer sources, and the presence of rare species (e.g., fishes, aquatic macroinvertebrates, rare plants, etc.) have been documented for a number of large springs in arid regions of the western U.S. (e.g., Brune 1975, Harrill et al. 1988, Thomas et al. 1996), but basic information describing the physical and biological characteristics of most springs is limited. This paucity of knowledge has stifled spring management strategies and little attention has been given to balancing human use with maintaining their ecological integrity (Shepard 1993). As a consequence, most springs have been degraded by human activity and few springs resemble their historic biological and environmental condition (Shepard 1993, Sada et al. 2001, Sada and Vinyard 2002).

Erman (2002), Sada et al. (2005), and Fleishman et al. (2006) found predicting the species composition of aquatic and riparian communities at individual springs to be difficult, which they attributed to interacting factors of phenology, spring isolation and colonization-extinction dynamics. Although biological predictions at individual springs are difficult, knowledge is sufficient to describe relationships between spring environments and functional characteristics of aquatic and riparian communities. In springs unaffected by human activity, water chemistry (which is affected by climate, geology, topography, and aquifer characteristics), temperature, spring morphology, landscape association, and persistence are primary factors influencing aquatic communities, and soil moisture, chemistry, and soil structure and particle size are factors that most affect riparian vegetation (Resh 1983, Knopf et al. 1988, Cushing 1996, McCabe 1998, Castelli et al. 2000). Within boundaries set by the physicochemical environment, spring environments also change from the source (eucrenal environments) to the downstream limit of water. In persistent springs, variability in eucrenal environments is low compared to downstream reaches where the aquatic environment is increasingly influenced by temporal variability in air temperature, discharge, and water chemistry (McCabe 1998). These characteristics are contrary to lotic systems (streams and

ivers), where environmental variability is greatest near the source and lowest downstream (e.g., Hynes 1970, Vannote et al. 1980). Because of these spatial differences in variability, eucrenal aquatic communities are often dominated by species that are relatively intolerant of environmental variability and hypocreanal (downstream) communities are tolerant of greater variability. Springs that are unaffected by scouring floods also differ from lotic systems because of the absence of channel-forming processes, which are important environmental process that structure riparian and aquatic communities (McCabe 1998).

The diversity of aquatic species is usually lowest near spring sources, and increases downstream because of changes in thermal regime, suspended solids, water chemistry, and nutrient availability (Minckley 1963, Ward and Dufford 1979, Meffe and Marsh 1983). Similar to lotic systems, faunal diversity in springs may also be attributed to other factors such as physical habitat characteristics and microhabitat diversity. Species richness is generally correlated with heterogeneity in substrate composition, current velocity, and eucrenal and hypocreanal morphology (Williams and Danks 1991, Ferrington 1998). Sada et al. (2005) and Fleishman et al. (2006) found aquatic and riparian diversity also increased with spring size (ergo discharge). Aquatic communities in springs include many species that also occupy lotic and lentic systems, but some springs are also inhabited by crenobiontics (obligate spring-dwelling species) that are often weakly vagile and limited in distribution (e.g., Taylor 1985, Hershler 1998, Schmude 1999). In persistent springs with good water quality and unaffected by stressors such as scouring floods and human-caused disturbance, riparian zones consist of a woody overstory (willow [*Salix*], birch [*Betula*], roses [*Rosa*], and aspen [*Populus*] and an understory of sedges [*Carex*, *Juncus*], spike-rush [*Eleocharis*], and bullrush [*Scirpus*]). Vegetation near the source is typically dense and dominated by sedges or woody vegetation. The density of vegetation decreases downstream and the canopy opens where water is limited. When amphibians occur at a spring, they generally avoid eucrenal areas and prefer hypocreanal, open habitats (Bradford et al. 2003).

Natural and human stressors similarly influence the structure of aquatic and riparian communities. Springs with high water temperatures, high chemical concentrations, or that are disturbed by natural events (drought, fire, flood, avalanche scouring, etc.) and human (reduced discharge from groundwater pumping or surface diversion, livestock trampling, impoundment, recreation, etc.) are harsh environments compared to persistent springs with cooler water and unaffected human or natural stressors. The influence of stressors on aquatic and riparian communities generally varies along a gradient of increasing frequency, and the duration and magnitude of stressors. Stressors to these communities are similar to those known for other aquatic and riparian systems (e.g., Resh et al. 1988, Smith et al., 1991, Stromberg and Patten 1992, Fleischner 1994), however, the effect on arid land spring biota appears to be more severe due to the naturally harsh arid environment, the isolation of springs from other aquatic systems, and challenges that these factors pose to organism dispersal and recolonization. As harshness increases, aquatic communities become less speciose, support fewer environmentally intolerant species (e.g., non-baetid mayflies, caddisflies, crenobiontics), and they are increasingly dominated by environmentally tolerant and vagile species (e.g., beetles, water boatman, and midges) (Sada et al. 2005). Harshness also affects riparian communities by decreasing diversity and ground cover, and increasing the abundance of upland and non-native species (Fleischman et al. 2006).

The chemical harshness of a spring is correlated with chemical concentration and water temperature. In harsh chemical environments (e.g., temperatures greater than 45°C, conductance greater than 1,500 microseimens/cm [μmhos], pH less than 5.0 and greater than 9, or frequent drying) fish and macroinvertebrates are scarce, and cyanobacteria dominate the aquatic community. Chemically harsh water also influences soil chemistry and riparian vegetation by limiting communities to species that are tolerant of high salinity and alkalinity (Brotherson and Rushforth 1987, Kristjansson and Hreggvidsson 1995).

Most arid land springs have been altered by livestock use and diversion, and reference springs are scarce (Shepard 1993, Sada et al. 1992, 2001). Intensive livestock use tramples riparian areas, increases sedimentation, and increases incident radiation. The biological consequences of livestock using springs are similar to those known for lotic systems (e.g., Fleischner 1994). Recreational use of springs may also trample riparian areas and affect spring biota (e.g., Sada 2001). Diversions decrease spring discharge, shorten spring brooks, and reduce aquatic habitat heterogeneity and the stability of the aquatic environment. Diversions may also affect water temperature, dissolved oxygen concentration, and pH. These changes affect aquatic life by increasing environmental variation and reducing the stability and extent of aquatic habitat. This reduces habitat for intolerant aquatic species that occupy eucrenal habitats relative to variable environments preferred by tolerant taxa in hypocrenal habitats. Lower discharge also decreases the aerial extent of riparian habitat and alters composition of the riparian community by reducing soil moisture. These effects are similar to changes documented for arid land lotic systems (e.g., Smith et al. 1991, Stromberg and Patten 1992). Springs are also diverted into impoundments. In these conditions, species that require flowing habitats are replaced by organisms adapted to lentic environments and the likelihood of non-native fish introductions increases.

METHODS

Springs in LAME were inventoried following Level I survey protocols prepared by Sada and Pohlmann (2006) (Appendix I). The foundation for these is based on a number of hydrological and biological studies of springs in the western U.S. and elsewhere (e.g., Ferrington 1995, Botosaneanu 1998, Meffe and Marsh 1983, Williams and Danks 1991, Thomas et al. 1996, Sada et al. 2005, Fleishman et al. 2006, and many other references that are cited herein) that have examined spring physicochemical conditions and their influence on spring-fed aquatic and riparian communities.

The inventory included all 89 sites listed in an existing LAME springs database. Field surveys included: 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) [all water features are herein referred to as 'springs' except when they are explicitly identified as wells, qanats, or other man-made features; man-made features were rare in LAME]. Level I surveys were developed to characterize salient aspects of each spring's aquatic and riparian environments (See Appendix I for a list of information collected at each spring and water feature). They are reconnaissance-level observations that focus on locating springs and generally assessing their biotic potential to facilitate management and prioritize the importance of individual sites. This

information is neither highly detailed nor accumulated in a manner that allows rigorous statistical analysis. Collection of highly quantified data requires much more detail, time, and substantially greater funding than Level I surveys. This type of information should also be compiled during monitoring programs that quantify spatial and temporal variation in physicochemical and biological elements of springs. Monitoring programs for water chemistry and riparian and aquatic systems in springs are also described in Sada and Pohlmann (2006).

Data for Lake Mead spring inventories were collected by field crews of two people who were trained to conduct Level I surveys during classroom and field studies. Efficacy and accuracy of the crews were evaluated during site visits when D. Sada observed data collection techniques and recording accuracy. Evaluations were recorded on standard forms shown in Appendix II. All Level I survey elements (Appendix I) were recorded at most springs, but isolated elements were omitted when equipment failed, a spring was dry (hence water chemistry and aquatic environmental characteristics were omitted), or rarely by inadvertent neglect. These instances were uncommon and reasons data were not collected were recorded as notes in the database.

Data collected from each spring are compiled in an Access[®] database that was developed by U.S. National Park Service database managers. Data to prepare this report were analyzed by querying this database. For this report, spring characteristics were examined by pooling information from all park springs.

Matrix analyses were conducted to 1) prioritize springs for long-term monitoring and 2) prioritize springs where restoration programs will maximize the conservation of Lake Mead's water resources, aquatic and riparian biodiversity, and rare aquatic species. These analyses considered spring size, aquatic habitat persistence, the occurrence of important plants and animals (rare and non-native species), ease of access, and potential influence of stressors on riparian and aquatic communities. (e.g., drying, scoured by flooding, human recreation, diversions, etc.). For the monitoring analysis highest priority springs are easily accessed, occupied by rare animals, support high species richness (ergo are larger with long spring brooks), and minimally disturbed by natural or anthropogenic factors. These factors were selected because easy access is necessary to install and maintain equipment, and large springs and springs occupied by rare species are persistent and minimally affected by natural stressors. In addition, these sites are usually the most important to management because they support the most diverse riparian and aquatic communities, and the absence of natural stressors enhances opportunities to identify anthropogenic factors that stress spring communities. Suitability for monitoring is lower at remote and/or disturbed springs because it is difficult to install and maintain equipment and the elevated incidence of disturbance demonstrably alters biotic communities by reducing species richness and limiting communities to species that are tolerant of harsh conditions. Elements and rating values included in each matrix are shown in Tables 1 and 2.

Table 1. Elements and ranking values used to rank springs in terms of their utility to serve as effective LAME monitoring sites. Each spring was ranked by evaluating each matrix criterion and summing the rating values for all criteria.

Monitoring Priority Elements	Rating Value
Presence of Important Aquatic Species ¹	Absent = 1, 1 Present = 10, >1 Present = 15
Ease of Access ²	1 or 2 = 0, 3 = 5, 4 = 10, 5 = 15
Spring Brook Length ³	< 50 = 2, ≤ 200 ≥ 50 = 5, ≤ 500 > 200 = 7, > 500 m = 10,
Scouring ⁴	Frequent = 0, Occasional = 5, None = 10
Aquatic Habitat Persistence ⁵	Ephemeral = 0, Persistent = 10
No. Native Tree Species Present ⁶	Absent = 0, 1 spp. = 5, 2 spp. = 10, > 2 spp. = 15
Human Disturbance ⁷	Slight/Unmodified = 0, Moderate = 10, High = 7

¹ Springs with either 1 rare species or amphipod rated 10, springs with >1 rare species or amphipod rated 15, springs without these species rated 0.

² The Level I protocol ranks ease of access from 1 to 5, with 1 being springs that are difficult to access and can be reached by hiking across country and 5 being springs easily accessed by a high-quality dirt road.

³ Length is the estimated distance in meters of the spring brook from the source to the end of contiguous flowing surface water. Higher species richness in aquatic and riparian communities is associated with longer spring brooks.

⁴ Scouring is based on the potential of scouring flood events. Frequent scouring is a natural stressor that decreases species richness of aquatic and riparian communities. These springs therefore have 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 vegetation (e.g., *Eleocharis*, water cress) and communities that include crenobiontic species or large numbers of Ephemeropterans, Plectopterans, or Trichopterans. Riparian vegetation associated with non-persistent waters includes more facultative wetland and upland species and macroinvertebrate communities are dominated by tolerant groups of animals. The presence of crenobiontic species indicates the spring has long-term persistence.

⁶ Palm, mesquite, willow, and cottonwood trees occurred at LAME springs. Higher ranking values are given to sites with greater number of trees. Greater tree diversity is indicative of more readily available water, higher structural complexity to the woody vegetation, and higher potential use of the site by birds and other animals.

⁷ Human disturbances (e.g., diversion, non-native ungulates, recreation, etc.) are considered because restoration is not needed for springs that are disturbed by natural events. Springs undisturbed by humans are ranked low because they need no restoration, moderately disturbed springs are ranked highly because quick action may prevent further declines in their biotic integrity. Highly disturbed springs are ranked lower because many are so badly disturbed that restoration is a very long-term process that requires substantial resources. These springs should be restored, but they are typically lower priority than actions needed to enhance moderately disturbed springs.

Table 2. Elements and ranking values used to evaluate the restoration priority of LAME springs. Each spring was ranked by evaluating each matrix criterion and summing the rating values for all criteria.

Restoration Priority Elements	Rating Value
Presence of Important Aquatic Species ¹	Absent = 1, 1 Present = 10, >1 Present = 15
Ease of Access ²	1 or 2 = 0, 3 = 5, 4 = 10, 5 = 15
Spring Brook Length ³	< 50 = 2, ≤ 200 ≥ 50 = 5, ≤ 500 > 200 = 7, > 500 m = 10,
Scouring ⁴	Frequent = 0, Occasional = 5, None = 10
Aquatic Habitat Persistence ⁵	Ephemeral = 0, Persistent = 10
No. Native Tree Species Present ⁶	Absent = 0, 1 spp. = 5, 2 spp. = 10, > 2 spp. = 15
Human Disturbance ⁷	Slight/Unmodified = 0, Moderate = 10, High = 7
Non-Native Species Presence ⁸	Absent = 0, Present = 10

¹ Springs with either 1 rare species or amphipod rated 10, springs with >1 rare species or amphipod rated 15, springs without these species rated 0.

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⁸ Sites with non-native species are ranked highly because it is important to control these species and discourage their spread into other portions of the Park.

For this report, environmental and biological characteristics of LAME springs were examined using most of the parameters measured and estimated during Level I surveys. Dissolved oxygen concentration and pH were not considered in this analysis because there was little variability observed among springs, these parameters exhibit wide temporal variability, and they weakly describe important features of LAME springs. Estimated substrate composition was also excluded from the analysis because these data are poorly suited to statistical analysis. Summaries were compiled by graphically categorizing characteristics of springs throughout LAME (Fig. 2 – Fig. 16).

RESULTS

A total of 89 springs were inventoried in LAME. Surveys were conducted during summer 2007. Springs were sparse ($0.015/\text{km}^2$) and scattered throughout LAME. Most springs were associated with intrusive igneous, volcanic, and clastic carbonate formations (Fig.1).

All but six LAME springs occurred below 1,000 m (~3,300 ft) elevation (Fig. 2) and most of them were accessed over a rough road using all-terrain vehicles or by hiking less than 2 km (1 mi) (Fig. 3). Many springs were adjacent to paved or good quality gravel roads. Estimated discharge was less than 10 l/min (~2 gal/min) for most springs (Fig. 4). Spring brooks were typically less than 50 m (~160 ft) long (Fig. 5), and most were less than 10 cm (~4 in) deep (Fig. 6) and 100 cm (~3.3 ft) wide (Fig. 7). Most springs were rheocrenes (Fig. 8) and water temperature was near ambient (between 10°C and 25°C) (Fig. 9), but the temperature of 40 springs was greater than 15°C, and several springs in Boulder Canyon were warmer than 40°C. Electrical conductance (EC) was greater than 1,000 μmhos in most springs (Fig. 10). High temperatures and EC indicates many LAME springs are relatively harsh chemical environments for aquatic life. The proportion of LAME springs with harsh chemical environments is high when compared to most springs in the Great Basin (Thomas et al. 1996). Primary woody vegetation at springs included mesquite (*Prosopis* sp.), willow (*Salix* sp.), and salt cedar (*Tamarix* sp.) (Fig.11). Wild grape (*Vitus* sp.) did not occur at any spring. Obligatory wetland vegetation (e.g., spikerush [*Eleocharis* sp.], cattail [*Typha* sp.], and watercress [*Rorippa* sp.]) occurred at approximately 20 percent of springs (Fig. 11). Emergent cover was less than 20 percent at most springs (Fig. 12) and bank cover was usually less than 50 percent (Fig. 13).

Important animals (amphibians, springsnails, amphipods, fish, and ostracodes) occurred in some LAME springs (Fig. 14). Amphibians were recorded at only one spring during these surveys (a red-spotted toad [*Bufo punctatus*]), but work by Bradford et al. (2003) reported this toad at several LAME springs and relict leopard frogs are known from seven LAME springs (Relict Frog Conservation Team 2005). Most LAME springs were either moderately or highly disturbed (Fig. 15). Natural disturbances (flooding, drying, and fire) were more common than human disturbance, which was mostly attributed to recreation and diversion (Fig. 16).

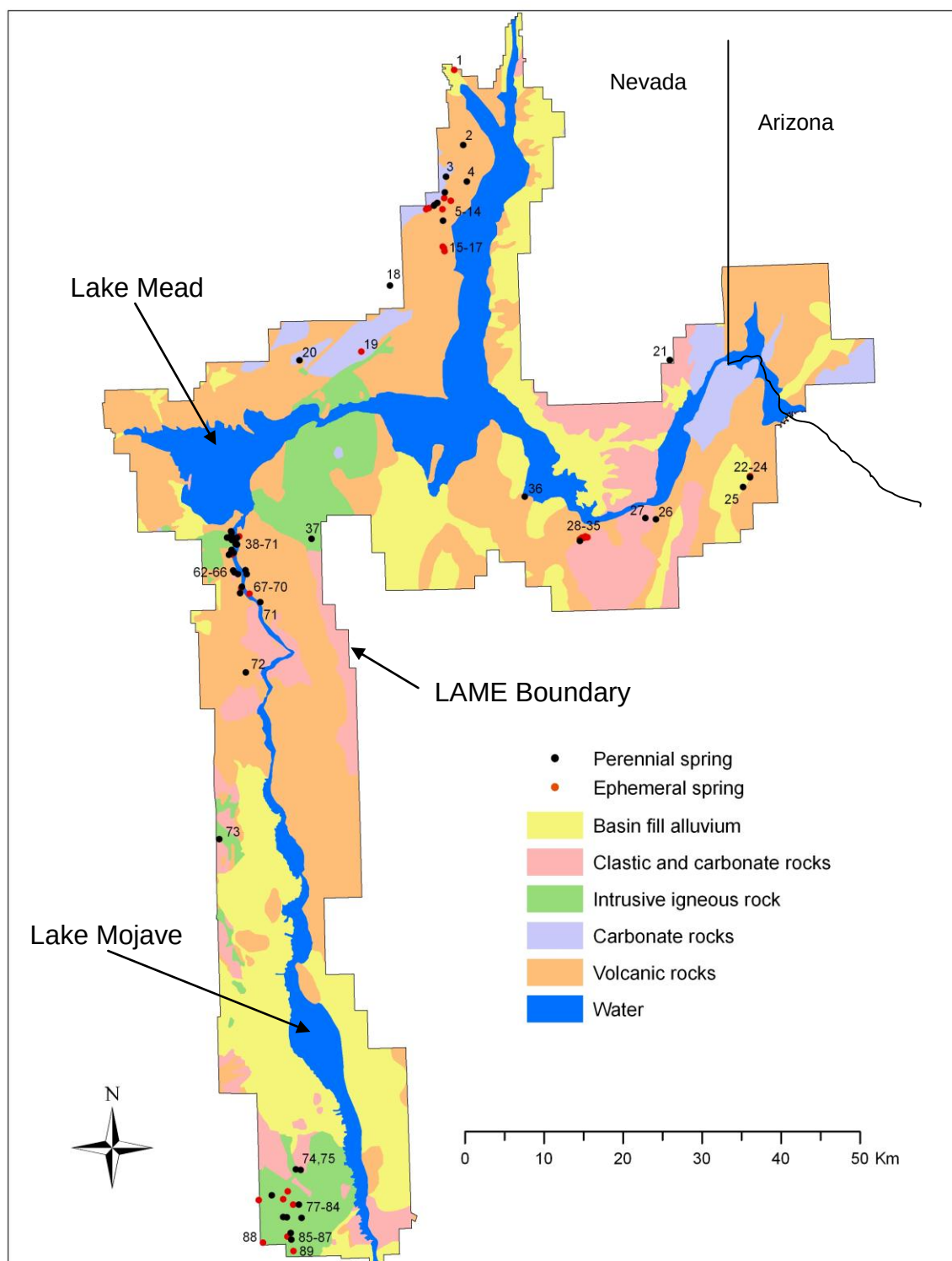


Figure 1. Geological map of LAME showing the location of perennial and ephemeral springs surveyed in 2007. Spring numbers and salient information for each spring are shown in Appendix III.

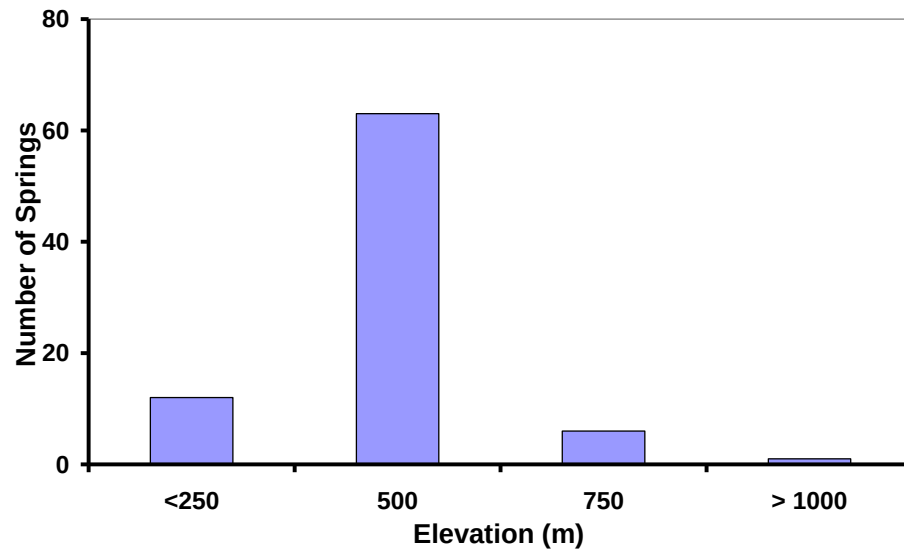


Figure 2. Frequency histogram of spring elevations in LAME.

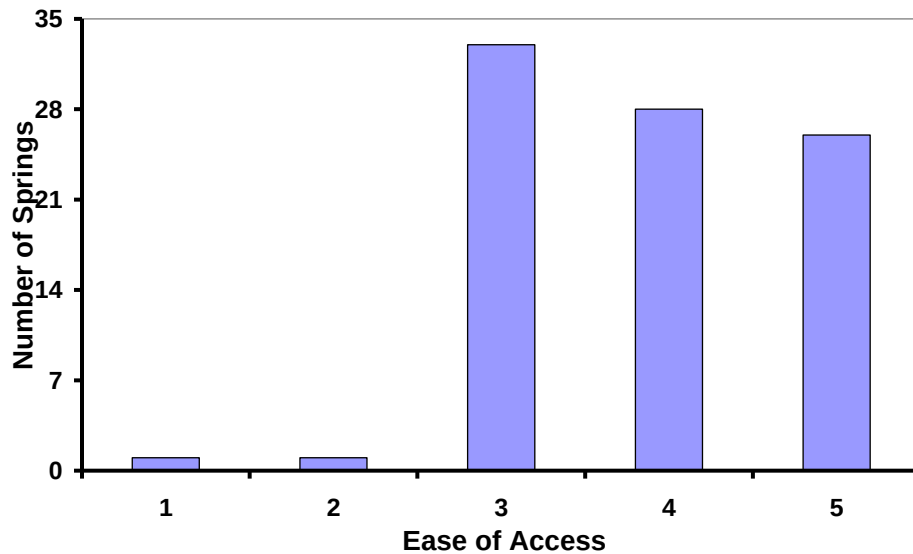


Figure 3. Frequency histogram showing accessibility of LAME springs surveyed in 2007. Category 1 = inaccessible sites, access only by cross-country hiking; Category 2 = sites that can be accessed only by arduous trail hike (e.g., > 5 miles); Category 3 = sites accessed by easy trail hike (e.g., 1 to 5 miles) and four-wheel drive vehicle; Category 4 = sites easily accessed by walking less than 1 mile or a two-wheel drive, high clearance vehicle; and Category 5 = sites immediately adjacent to high-quality gravel road or a paved road.

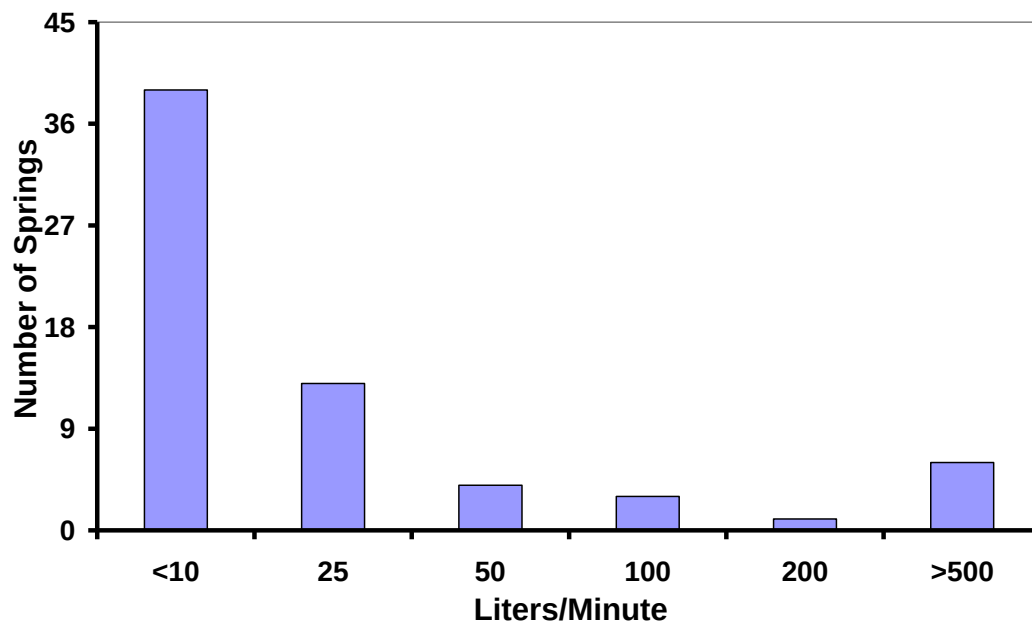


Figure 4. The frequency distribution of estimated discharge rates for LAME springs surveyed in 2007.

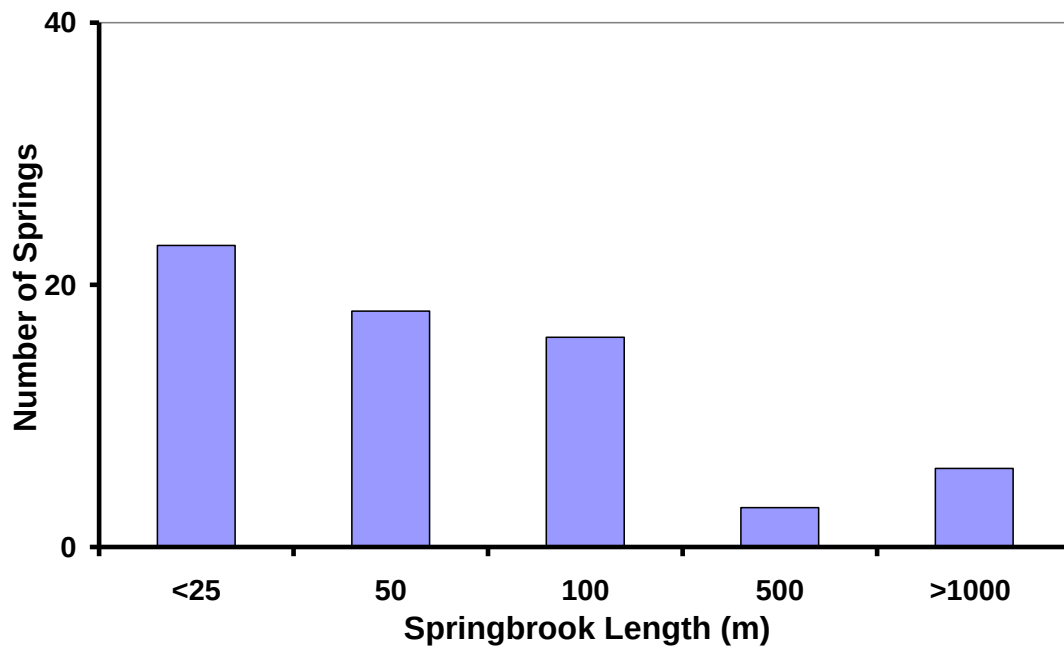


Figure 5. The frequency distribution for the estimated spring brook length in LAME during spring inventories conducted in 2007.

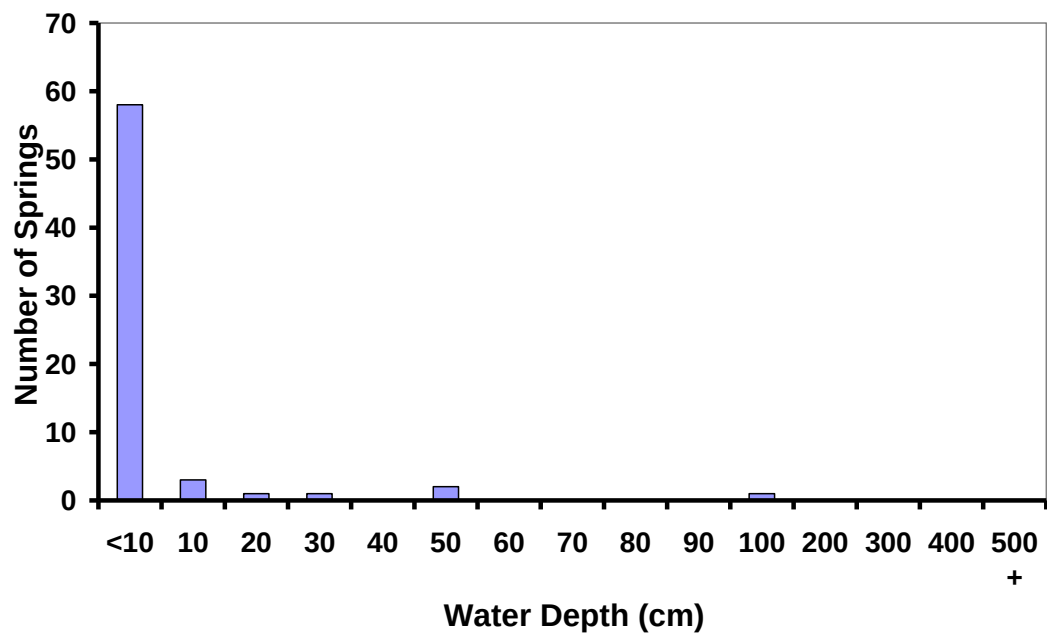


Figure 6. Frequency histogram for estimated average water depth of flowing spring brooks from LAME springs during 2007 surveys.

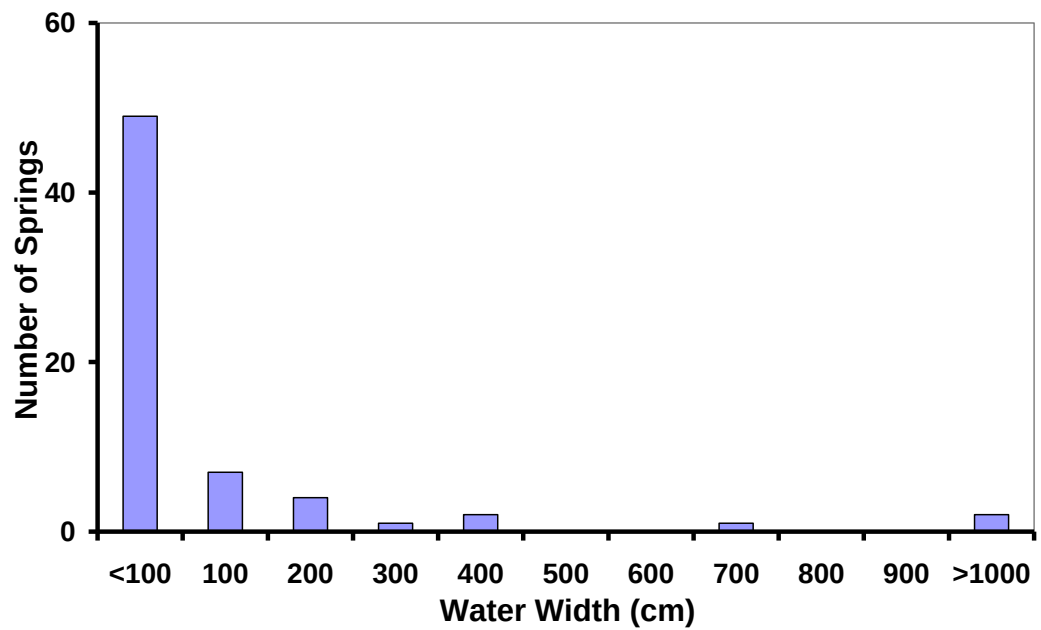


Figure 7. Frequency histogram for estimated average water width in flowing spring brooks at LAME springs during 2007 surveys.

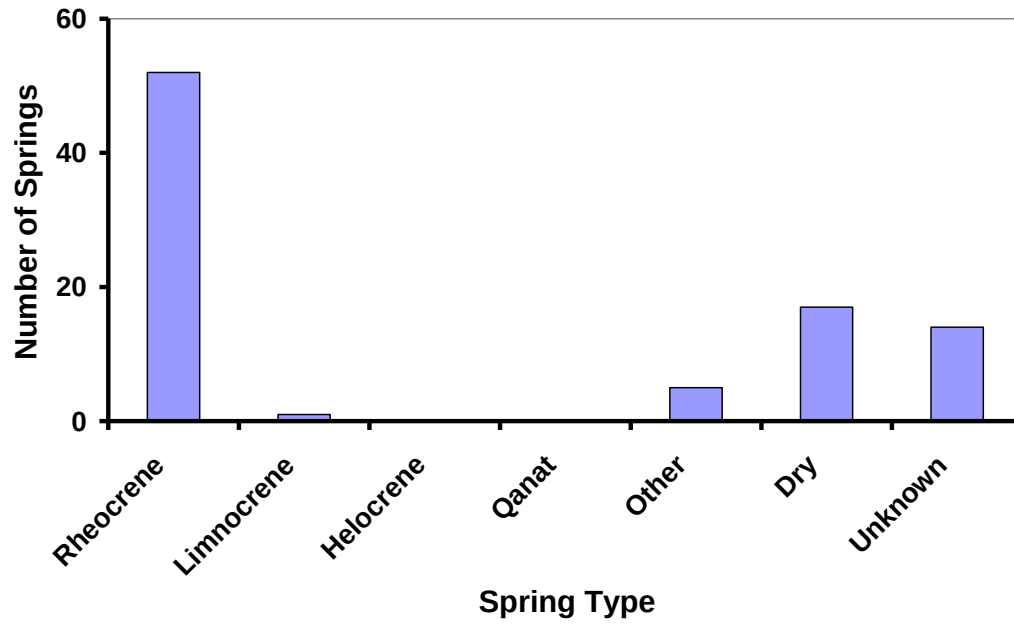


Figure 8. Frequency histogram for the types and morphology of springs surveyed at LAME during 2007 surveys.

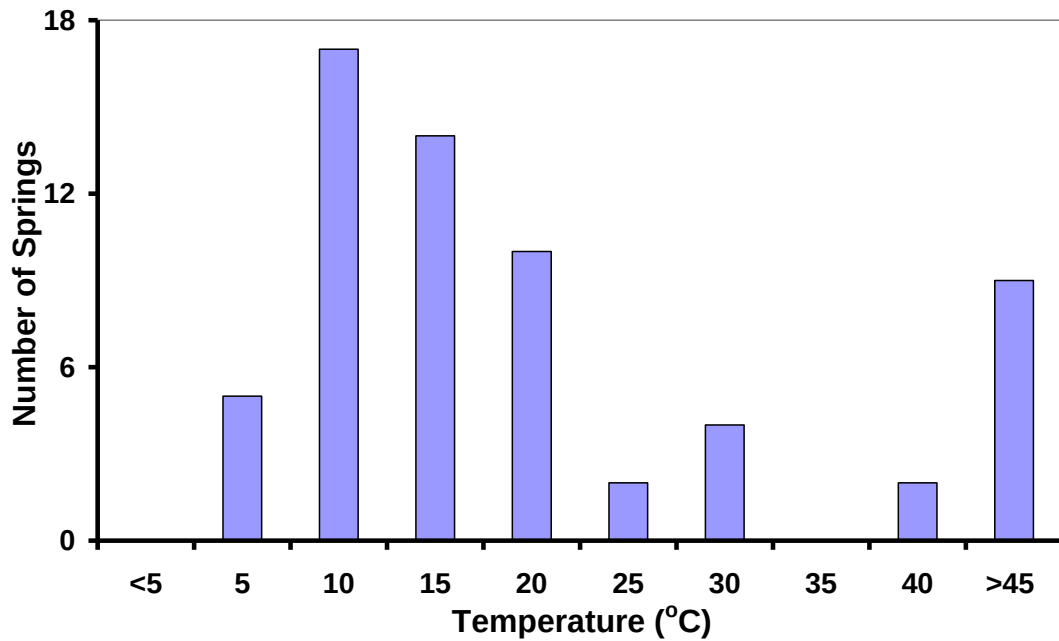


Figure 9. Frequency histogram for the water temperature of LAME flowing springs during 2007 surveys.

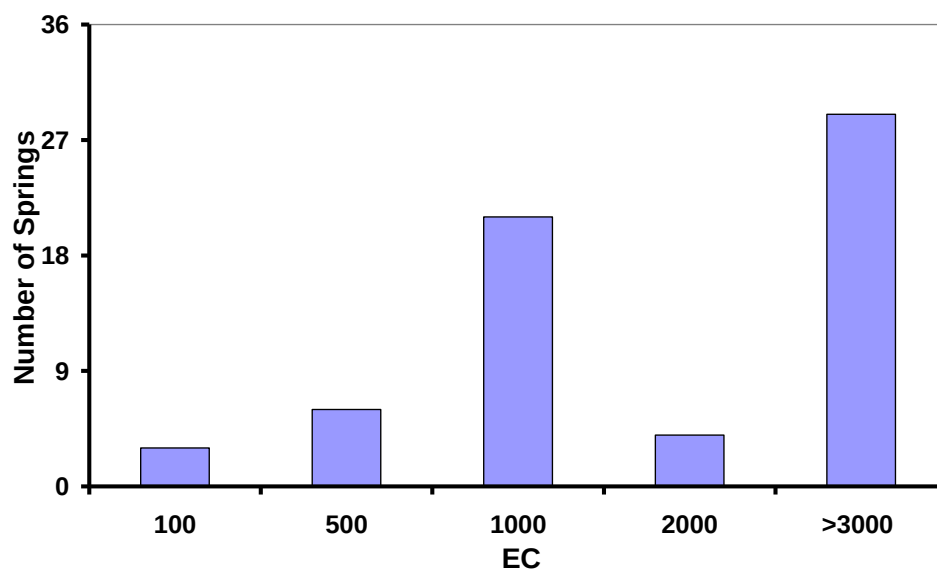


Figure 10. Frequency histogram for electrical conductance (EC in µmhos) at flowing LAME springs during 2007 surveys.

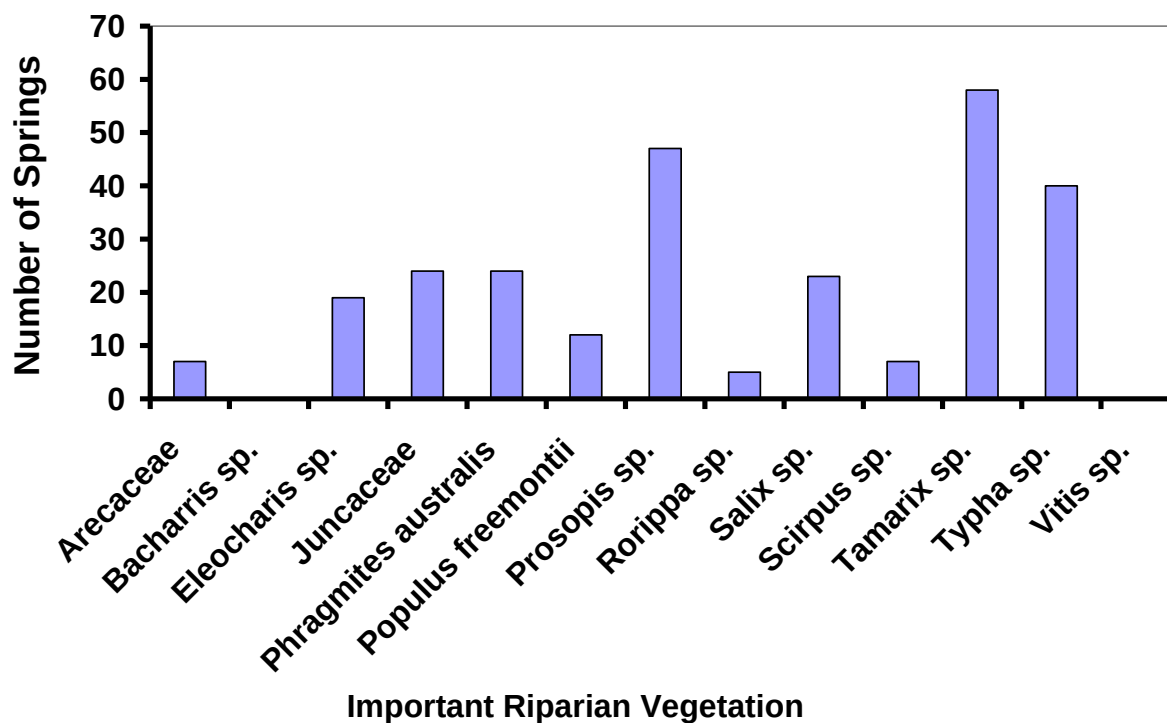


Figure 11. Frequency histogram for important riparian vegetation at flowing LAME springs during 2007 surveys.

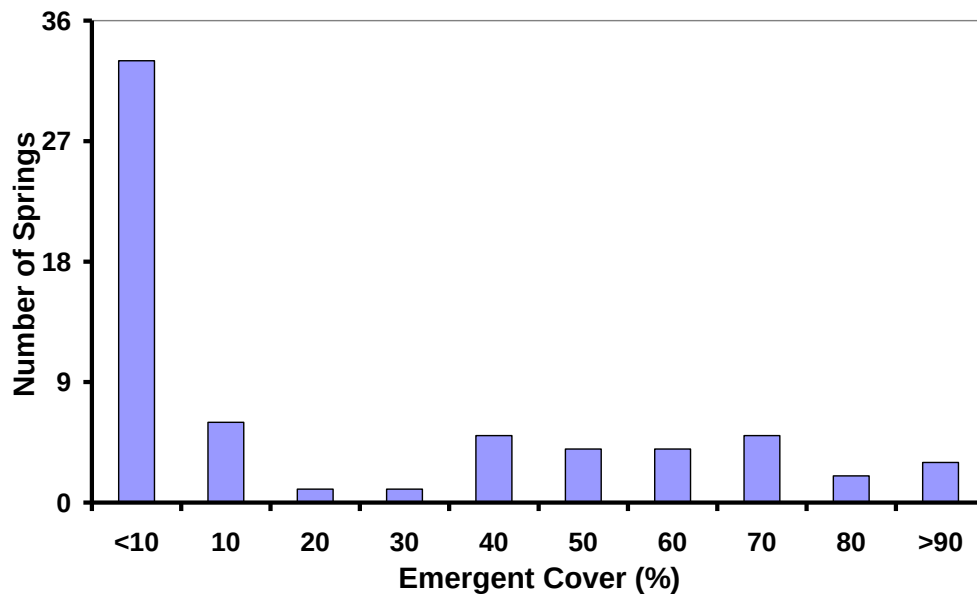


Figure 12. Frequency histogram for the estimated percent of spring brook wetted area covered by emergent vegetation at flowing LAME springs during 2007 surveys.

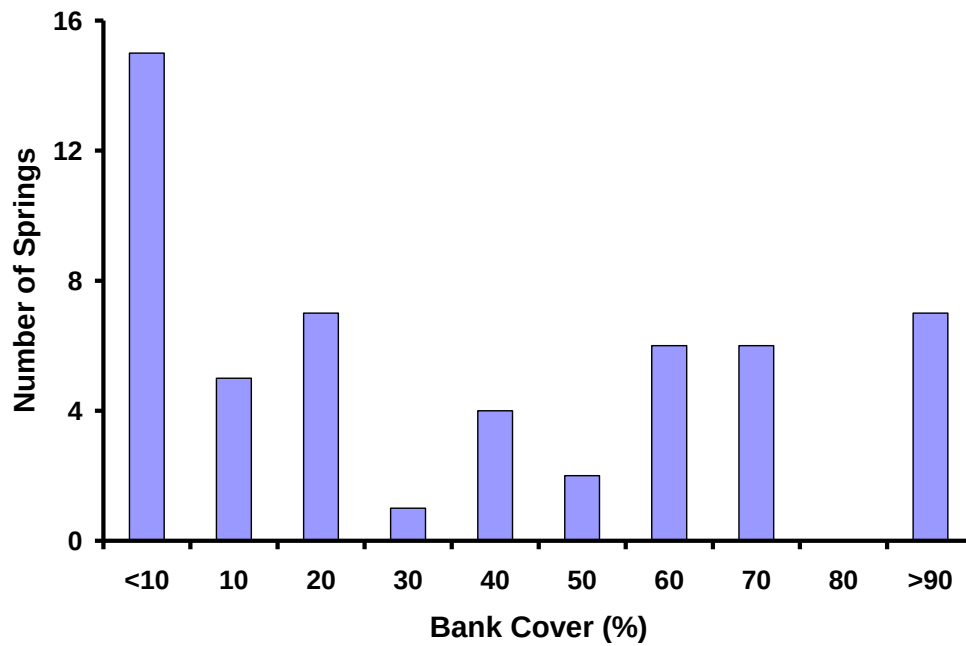


Figure 13. Frequency histogram for the estimated percent of spring brook banks covered by vegetation at flowing LAME springs during 2007 surveys.

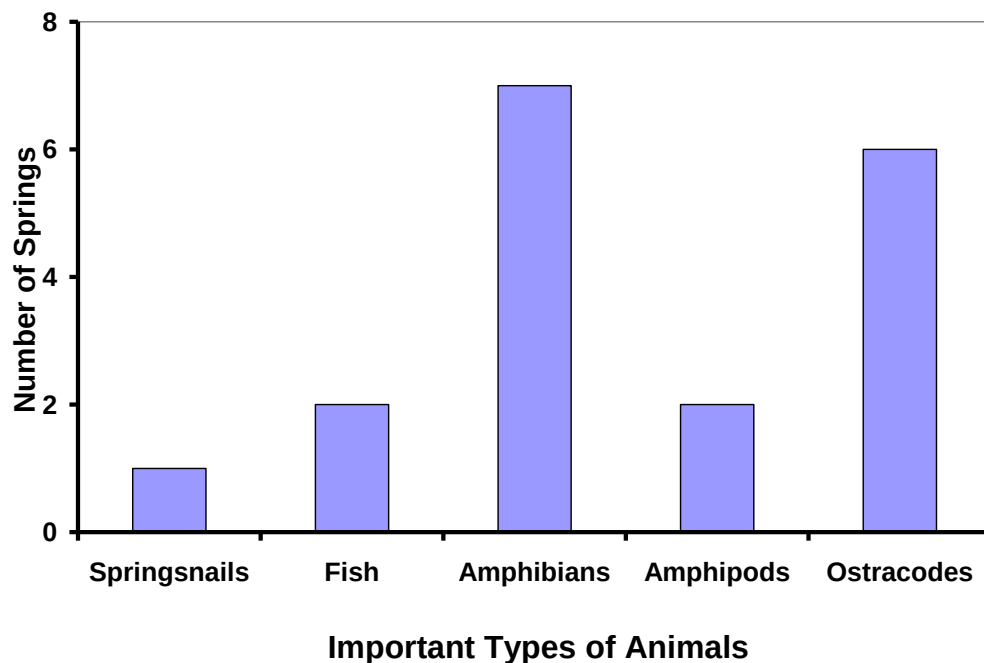


Figure 14. Frequency histogram showing the number of LAME springs with important aquatic animals during 2006 and 2007 surveys. Relict leopard frogs occur in seven LAME springs, but they were not observed during spring surveys. All fish are non-native and occur only in Rogers and Blue Point springs. Springsnails are extant only in Blue Point Spring and have been extirpated from Rogers Spring.

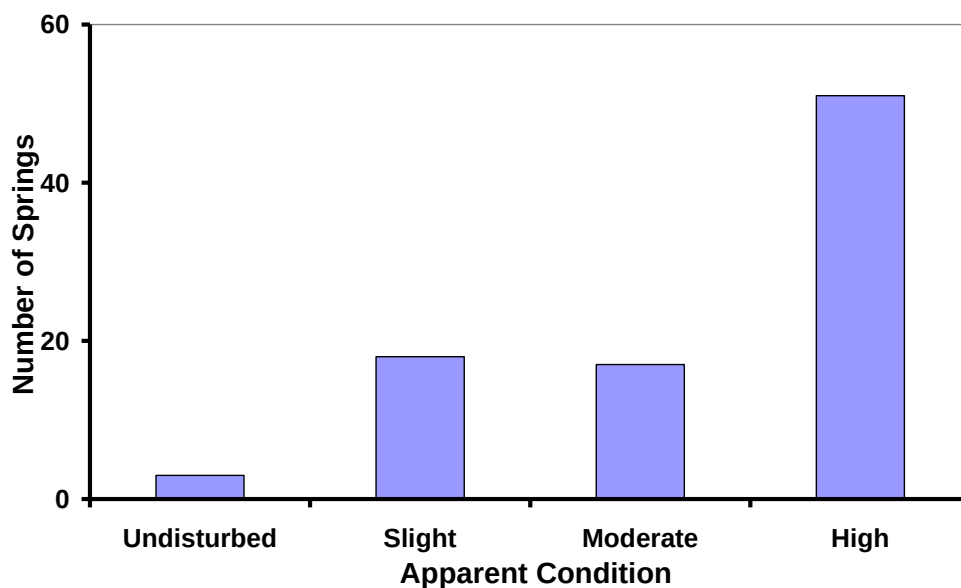


Figure 15. Frequency histogram showing levels of disturbance recorded at LAME springs during 2007 surveys.

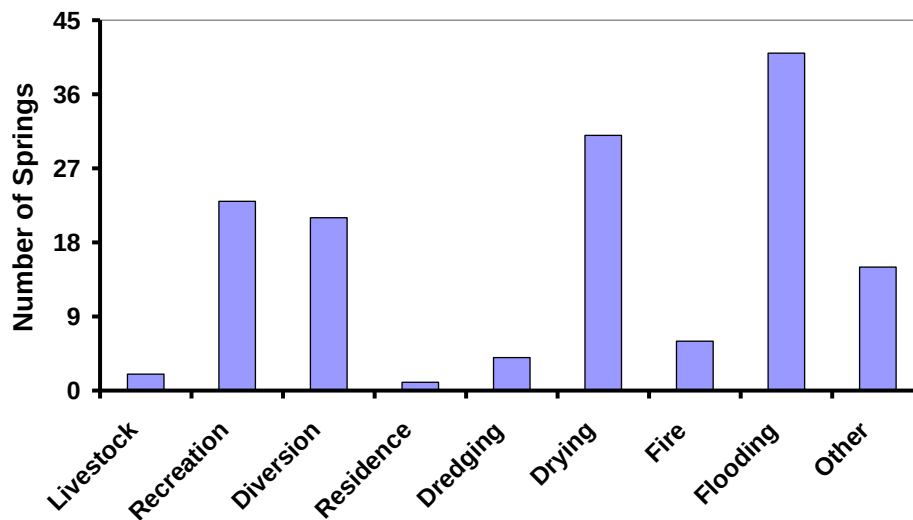


Figure 16. Frequency histogram for natural and human factors contributing to stresses recorded at LAME springs during 2007 surveys. Drying tally is only for springs that were dry during survey, not springs that may periodically dry. See Appendix III for springs that periodically dry.

Table 3. Regression equations and correlation coefficients for statistically significant ($p < 0.05$) regressions examining relationships between physical and chemical characteristics of LAME springs. Of the 26 analyses conducted to examine relationships between discharge, spring brook length, water depth, water width, dissolved oxygen concentration, water temperature, EC, and pH, only these five were significant.

Independent Variable	Dependent Variable	Regression Equation	R ²
-----	-----	-----	-----
Discharge	Spring Brook Length	$y = 2.682x + 58.24$	0.658
Discharge	Water Temperature	$y = 0.024x + 21.56$	0.101
Spring Brook Length	pH	$y = -0.0002x + 7.83$	0.102
Water Width	Water Temperature	$y = 0.0039x + 22.35$	0.127
Temperature	Dissolved Oxygen	$y = -0.055x + 7.80$	0.067

ENVIRONMENTAL RELATIONSHIPS AMONG SPRINGS

Relationships between physical and chemical characteristics among LAME springs were examined through regression analysis. Of 26 analyses examining relationships between discharge, spring brook length, water depth, water width, dissolved oxygen concentration, water temperature, EC, and pH, five were statistically significant ($p < 0.05$) (Table 3). Although statistically significant, low correlation coefficients for each relationship suggest that the explanatory utility of these regression equations is limited. Due to this, the importance of these relationships is difficult to discern and they may be statistically significant but environmentally unimportant.

Only the relationship between temperature and dissolved oxygen concentration is easily explained because these variables should be inversely correlated. Low dissolved oxygen concentrations occur in higher water temperatures. Other relationships are difficult to understand and cannot be easily explained by redox reactions, geology, or other factors. Although relationships between these environmental factors are weak, it is important to recognize that many of these factors are important to aquatic and riparian communities (e.g., McCabe 1998, Sada and Nachlinger 1998, Sada et al. 2005, Fleishman et al. 2006).

Monitoring and Restoration Priorities

A prioritized list of monitoring and restoration springs is shown in Table 4. Highest priority monitoring springs in LAME were persistent, easy to access, not scoured by floods, supported rare aquatic species, several species of native woody vegetation, and minimally affected by human activity. These springs are also priority for management because they generally have the highest richness of aquatic and riparian species and provide the greatest amount of habitat for terrestrial species. These include Rogers, Blue Point, Bitter, and Grapevine Wash springs. Highest priority restoration sites include these springs in addition to Grapevine Springs in Arizona and Nevada, Sauna Cave, the two Pupfish Springs due to their moderate human disturbance, spring brook length, and minimal influence by drying and scouring.

These lists provide guidance for resource managers but they should not be considered as absolute directives. Selection of sites should be made after the purposes and goals of monitoring and restoration programs have been defined. This process will identify priority issues and guide site selection to springs that may address specific management issues. For instance, sites used to assess the influence of groundwater pumping on springs should be at lower elevations and vulnerable to pumping. It would be inappropriate to select high-elevation sites to assess pumping issues because mountain-block springs are rarely affected by pumping. Springs used to assess the influence of non-native species should be located where they may be affected and not outside of their distribution or sites where introductions are improbable (e.g., sites with harsh water chemistry). If long term trends in spring condition are to be examined, springs should be randomly selected throughout LAME and represent the physicochemical variety of its springs.

DISCUSSION

Arid land springs in the western U.S. are important water sources for wildlife and humans, provide information for groundwater investigations, and some are occupied by rare fishes, amphibians, mollusks, insects, crustaceans, and plants (e.g., Minckley and Brown 1982, Williams et al. 1985, Hershler and Sada 1987, Harrill and Thomas 1988, Thomas et al. 1996, Sada and Vinyard 2002, Smith et al. 2002, Relict Leopard Frog Conservation Team 2005). They are also “biodiversity hotspots” that support a large proportion of the aquatic and riparian species in arid regions (Fisher et al. 1972, Hubbs 1995, Myers and Resh 1999).

Although the importance of springs has been recognized for some time, most studies have been a component of groundwater investigations and have focused on larger, accessible springs (e.g., Harrill et al. 1988, Thomas et al. 1996) or springs occupied by crenobiontic species (e.g., Hubbs 1995, Hershler 1998, Schmude 1999). Most springs have not been visited by natural resource specialists, and their biotic and abiotic characteristics are largely

Table 4. Monitoring and restoration priority springs in LAME. Rating elements are matrix scores assigned using elements described in Table 1 for monitoring and Table 2 for restoration. Only the 65 highest priority sites are shown, the remaining 24 are small with low biological value. No. = spring number shown in Appendix III, Access = ease of access to spring, Length = estimated spring brook length, Scouring = severity of scouring by floods, Human Dist. = level of human disturbance, Aquatics = presence of rare aquatic species, Persistence = likelihood of drying, Non-Natives = presence of non-native species, Veg = score for number of native trees in riparian community, Monitoring = monitoring priority, and Restoration = restoration priority.

Spring Name	No.	Rating Elements									
		Access	Length	Scouring	Human Dist.	Aquatics	Persistence	Non-Natives	Veg	Monitoring	Restoration
Rogers Spring	10	15	10	10	7	15	10	10	5	65	82
Bitter Spring	18	15	10	0	7	10	10	10	15	60	77
Blue Point Spring	5	10	10	10	0	15	10	10	5	60	70
Grapevine Wash Spring	24	15	2	10	0	10	10	0	10	57	57
Grapevine Spring AZ	25	5	10	10	0	10	10	10	10	55	65
Grapevine Spring NV	82	10	5	10	0	10	10	10	10	55	65
Sacatone Spring Main (Lower)	81	10	5	10	0	10	10	0	10	55	55
Scirpus Spring	8	5	7	10	0	10	10	10	10	52	62
Monkey Cove Spring	36	15	5	10	0	1	10	10	10	51	61
Salt Spring	28	15	2	10	0	1	10	10	10	48	58
Kelsey Spring	1	15	2	10	0	10	0	10	10	47	57
Nevada Hot Spot	50	15	2	10	0	10	10	10	0	47	57
Grapevine Canyon Spring	84	10	5	10	0	1	10	10	10	46	56
Horsethief Canyon	37	5	10	5	0	1	10	10	15	46	56
Sauna Cave	42	15	5	10	10	1	10	10	5	46	66
Gnatcatcher Spring	6	15	5	5	0	5	0	0	15	45	45
Pupfish Cold Spring	38	15	5	5	7	10	10	10	0	45	62
Pupfish Hot Spring	9	15	5	5	7	10	10	10	0	45	62
Moss Spring	83	5	2	10	0	1	10	10	15	43	53
Corral Spring	11	5	2	5	10	15	10	10	5	42	62
South Pipe Spring	74	5	2	5	0	10	10	10	10	42	52
Boy Scout Hot Spring	59	10	10	0	10	5	10	10	5	40	60
Salt Cedar Hot Spring	62	10	10	0	0	5	10	10	5	40	50
Hot Spring 2 Unnamed	52	15	5	10	0	1	10	0	0	41	41

Table 4. Monitoring and restoration priority springs in LAME (continued).

<u>Spring Name</u>	<u>No.</u>	Rating Elements									
		<u>Access</u>	<u>Length</u>	<u>Scouring</u>	<u>Human Dist.</u>	<u>Aquatics</u>	<u>Persistence</u>	<u>Non-Natives</u>	<u>Veg</u>	<u>Monitoring</u>	<u>Restoration</u>
Nevada Falls	67	15	5	10	0	1	10	10	0	41	51
Palm Tree Hot Spring B	54	10	5	10	10	1	10	10	5	41	61
Valley of Fire Upper Spring	3	15	10	5	10	1	10	10	0	41	61
Dripping Spring	86	10	2	10	0	1	10	10	5	38	48
Willow Spring	77	10	2	10	0	1	10	0	5	38	38
Arizona Hot Spot 1	46	15	2	5	0	5	10	10	0	37	47
Sugarloaf Spring	48	5	5	0	0	1	10	10	15	36	46
Valley of Fire Wash Lower Spring	4	5	7	10	0	1	10	0	2	35	35
Salt Cedar 2 Spring (Cold)	63	10	5	0	0	5	10	10	5	35	45
Burro Spring LAME	27	15	2	10	10	1	0	10	5	33	53
Cottonwood Spring	20	5	2	5	10	1	10	10	10	33	53
Gold Strike Nevada Hot Spring Lower	51	10	2	10	10	1	10	10	0	33	53
Granite Cove Spring Unnamed	26	5	2	10	10	1	10	10	5	33	53
Cottonwood East Spring	21	10	5	5	0	1	0	10	10	31	41
Pipe Springs Canyon Unnamed Spring	85	5	5	5	0	1	10	10	5	31	41
Arizona Hot Spring	64	10	7	0	7	1	10	0	0	28	35
Bighorn Sheep Spring	69	5	7	0	0	5	10	10	5	32	42
Boy Scout Cold Spring	60	10	5	0	10	5	10	0	0	30	40
Bridge Canyon Lower Spring Unnamed	89	10	2	5	0	10	0	10	1	28	38
Latos Pools	72	5	2	0	0	1	10	10	10	28	38
Palm Tree Cold Spring	55	10	7	0	0	1	10	10	0	28	38
Sacatone Spring Unnamed	79	5	2	5	0	1	0	0	15	28	28
Vaghini Spring	43	15	2	0	0	1	10	0	0	28	28

Table 4. Monitoring and restoration priority springs in LAME (continued).

		Rating Elements									
<u>Spring Name</u>	<u>No.</u>	<u>Access</u>	<u>Length</u>	<u>Scouring</u>	<u>Human Dist.</u>	<u>Aquatics</u>	<u>Persistence</u>	<u>Non-Natives</u>	<u>Veg</u>	<u>Monitoring</u>	<u>Restoration</u>
Aztec Spring	73	5	5	5	10	1	10	0	0	26	36
Dawn Cold Spring	57	10	5	0	0	1	10	10	0	26	36
Dawn Hot Spring	56	10	5	0	0	1	10	10	0	26	36
Getchel Spring	2	5	5	5	0	1	10	10	0	26	36
Gold Strike Nevada Hot Spring Upper	40	5	10	0	7	1	10	10	0	26	43
Palm Tree Hot Spring A	53	10	5	0	0	1	10	10	0	26	36
Rogers Bay Spring Unnamed	14	5	5	0	0	1	10	0	5	26	26
Salt Spring Bay 1 Unnamed	30	5	5	10	0	1	0	0	5	26	26
Bridge Canyon Spring	88	10	2	5	0	1	0	10	5	23	33
Dripping Canyon Upper Unnamed Spring	87	10	2	10	0	1	0	10	0	23	33
Quail Spring East	31	5	2	10	0	1	0	10	5	23	33
Sacatone Spring	80	10	2	10	0	1	0	10	0	23	33
Salt Seep 3 Unnamed	32	5	5	5	0	1	0	10	5	21	31
Black Canyon Spring 2 Unnamed	66	10	2	0	10	1	0	0	5	18	28
Jacobs Spring	44	15	2	0	0	1	0	0	0	18	18
Sugarloaf Seep	49	5	2	5	0	1	0	10	5	18	28
Sandstone Spring	48	5	2	5	10	1	0	10	0	13	33
Gold Strike Canyon Upper	40	5	2	0	10	1	0	10	0	8	28

unknown. This paucity of information challenges management to understand issues, set goals, track changes in condition, and overcome threats to arid land springs caused by diversion of surface waters, groundwater pumping (Minckley and Deacon 1968, Mayer and Congdon 2007), invasive species, and non-native ungulates (e.g., Sada and Vinyard 2002). Management is also challenged by its ability to accurately recognize differences in spring condition and identify the factors affecting aquatic and riparian communities in the wide diversity of springs. Because of this diversity, it is appropriate for management to differ among sites because it may focus on rare species at some springs, while at others, riparian vegetation providing roosting, nesting, and feeding habitat for wildlife may be most important. Additionally, some springs have been unaffected by humans but they are disturbed or harsh due to natural factors (e.g., drying, scouring, or harsh chemistry). At these springs, differences in management may have little effect on condition or biotic potential. To accommodate for these challenges, design of appropriate management must integrate knowledge of a spring's existing functional characteristics, its natural potential, influencing human and natural factors, and consider how management can influence functional characteristics of its biotic communities. Aquatic and riparian communities disturbed by natural and human factors are similar and characterized by the absence of crenobiontic species, low species richness, and species that are tolerant of harsh conditions (Sada et al. 2005, Fleishman et al. 2006). Springs affected by natural and human factors differ, however, in their biological potential. Management will have relatively minimal affect on springs influenced by natural factors but management for low levels of human disturbance will increase species richness, reduce the presence of tolerant species, and potentially conserve rare species. Relationships between the environment and characteristics of aquatic and riparian communities are illustrated as a conceptual model in Figure 17.

Aquatic systems in LAME include springs, Lake Mead, and a small portion of the lower Virgin River. These systems support a wide diversity of aquatic life, but the structure of many vertebrate and invertebrate aquatic communities bear little resemblance to natural, historic conditions. Rivers and some of the largest springs have been impounded and diverted, and most rivers and some spring brooks have been replaced by lake or ponds. These habitat modifications functionally changed free-flowing rivers into lentic systems, which altered riparian and aquatic communities and facilitated establishment of many non-native fishes (Deacon et al. 1964, Hubbs and Deacon 1964, Minckley 1979).

The spring inventory program initiated by the Mojave Network of National Parks is the first known landscape-scale inventory of springs in the western U.S. Information from these inventories qualitatively describes salient characteristics of their environments, aquatic and riparian biota, and ecological function to inform assessments of how human use and their natural environment affect their condition and ecology. A total of 89 springs (72 of which were flowing during surveys) were located and inventoried in LAME. Most LAME springs were relatively harsh environments because of natural events such as drying, scouring, or harsh water chemistry (e.g., high temperature and EC). Only 30 percent of springs in the Park were unaffected by drying or scouring (Table 5), and median EC was greater than 2,100 μmhos (Table 6). This high median EC was almost four times greater than records compiled for springs during surveys in other Mojave Network Parks (Table 6) and it may be attributed to evaporates dissolved as groundwater passes through the Horse Springs Formation (Longwell et al. 1965). The naturally harsh conditions in Mojave Network springs are not unique to LAME and they appear to characterize springs throughout the Network, where

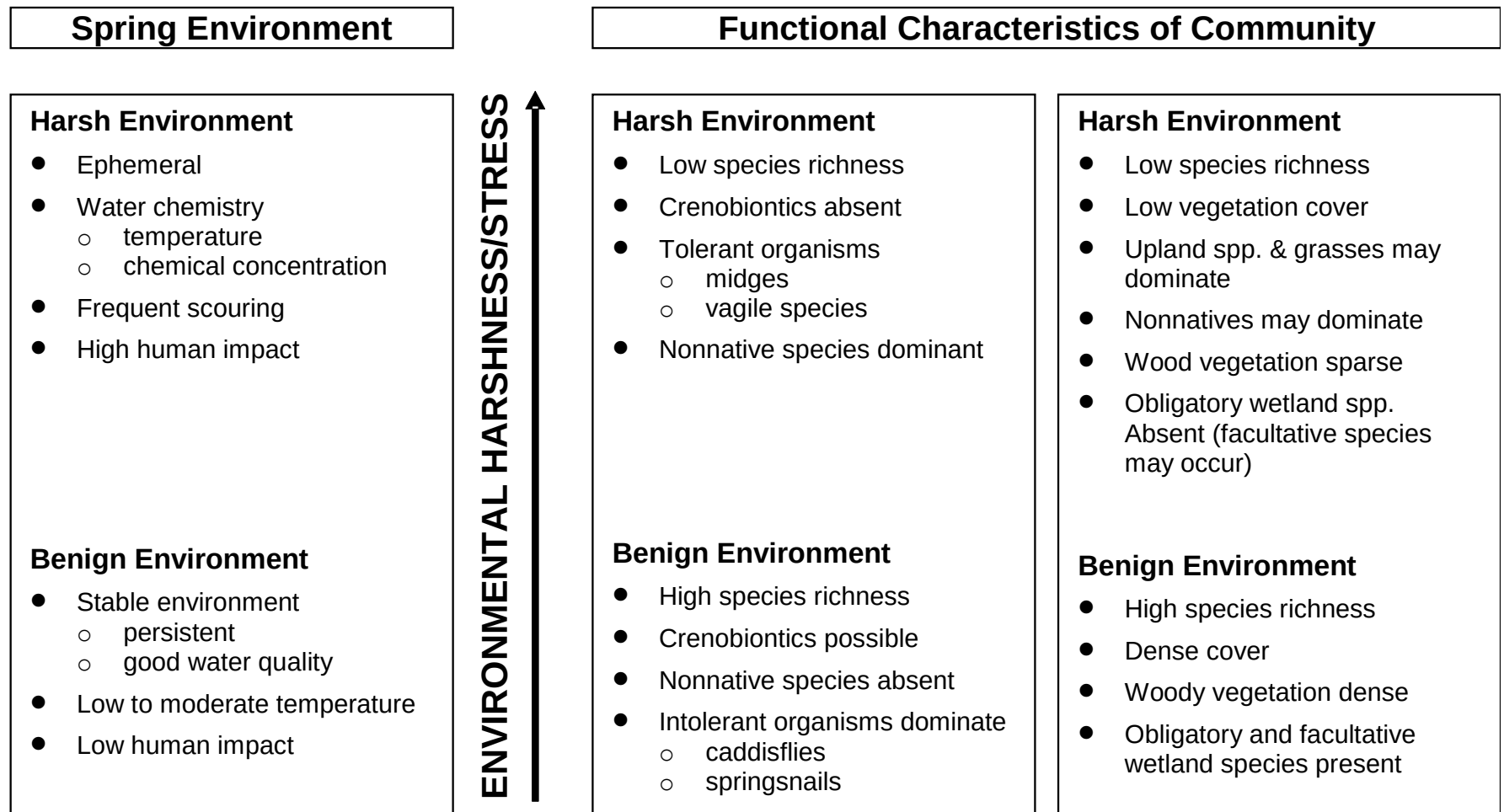


Figure 17. Conceptual model showing the relationship between environmental stress and biological indicators of arid land springs.

Table 5. The number of springs surveyed in the Mojave Network of National Parks and the percent of springs in each park that were disturbed by drying and scouring (natural factors) and human factors (See Appendix III for details regarding each LAME spring). Data collected during spring inventories from 1999 – 2007. JOTR = Joshua Tree National Park, PARA = Grand Canyon—Parashnat National Monument, and DEVA = Death Valley National Park.

Park	No. Spgs.	Dry	Scoured	Human	Not Dry/Scour	Undisturbed
-----	-----	-----	-----	-----	-----	-----
LAME	89	36	46	46	29	6
JOTR	109	33	65	17	0	0
PARA	206	46	28	66	13	< 0.1
DEVA	762	51	36	32	27	11

Table 6. Median (range in parentheses) values of fundamental natural environmental factors influencing riparian and aquatic community structure in flowing springs surveyed in the Mojave Network of Parks during 1999 and the early 2000s. LAME = Lake Mead National Recreation Area, JOTR = Joshua Tree National Park, PARA = Grand Canyon-Parashant National Monument, DEVA = Death Valley National Park, SBL = spring brook length.

Factor	LAME	JOTR	PARA	DEVA
-----	-----	-----	-----	-----
Discharge (l/sec)	5 (1 - 1000)	2 (0.5 - 400)	10 (0.5 - 500)	2 (0.1 - 1000)
SBL (m)	70 (0.5 - 3500)	50 (1 - 1716)	20 (0.3 - 1000)	30 (1 - 5000)
EC (µmhos)	2126 (130 - 25490)	562 (67 - 2399)	768 (70 - 5400)	889 (50 - 159500)
Temp (°C)	18.7 (6 - 60.7)	12.3 (3.4 - 22.9)	19.7 (6.8 - 32.8)	14.6 (0.6 - 47.1)
Elevation (m)	399 (156 - 959)	1065 (609 - 1519)	1354 (342 - 2166)	950 (-114 - 2918)

drying and scouring affect more than 70 percent of springs in each desert park (Table 5). Effects of these harsh conditions are exhibited in biotic communities of LAME springs by the scarcity of obligatory and facultative wetland vegetation and crenobiontic species. Obligatory wetland vegetation, such as watercress (*Rorippa* sp.) occurred at less than 10 percent of springs, and facultative wetland vegetation (e.g., *Eleocharis* sp., *Juncus* sp.) each occurred at less than 30 percent of springs. Woody vegetation at springs included mesquite and non-native salt cedar, with occasional cottonwood and willow. The presence of salt cedar was prominent throughout the Park, especially at spring sites and the Lake Mead shoreline. Cheatgrass (*Bromus* spp.) was the only other non-native vegetation recorded. Molluscs are the only crenobiontic species known from LAME and they have been recorded only from Blue Point and Rogers Springs (they have been extirpated from Rogers Spring) (Hersher 1998, Sada, field notes). Crenobiontic and other important aquatic animals that are indicators of high quality springs and high species richness occurred at a total of 19 LAME springs. Blue Point Spring was inhabited by the greatest number of important aquatic species, including three molluscs and the relict leopard frog. Although not observed during these surveys, the Relict Leopard Frog Conservation Team (2005) reports this leopard frog occupies six other

LAME springs. Native fish have never been recorded from LAME springs, and fish occurred in only Rogers and Blue Point springs during spring surveys. All fish species were not native to LAME, and primarily introduced from aquaria.

The naturally harsh condition of LAME springs is exacerbated by human activity, which has altered 46 percent of its springs. Twenty-five springs were affected by both natural and human factors (see Appendix III), and only five springs were undisturbed by human or natural factors. All springs undisturbed by human or natural factors were also relatively harsh environments because their EC values were greater than 1,000 μmhos . Diversion and recreation were the most frequently observed human disturbances, but springs were also disturbed by dredging and non-native ungulates. The proportion of LAME springs altered by human activity is relatively low compared to other portions of the Great Basin and Mojave Desert, where more than 75 percent of springs are moderately or highly disturbed by livestock and/or diversion (e.g., Sada et al. 1992, Sada and Nachlinger 1998). Although almost one-half of LAME springs were disturbed by human activity, this proportion is lower than what was observed in PARA springs and higher than that recorded in DEVA and JOTR (Table 5). Environmental characteristics of LAME springs were generally distinct from other Mojave Network parks because of their low elevation, high EC, and relatively high temperature (Table 6).

The relative influence of many environmental characteristics on spring biota can be qualitatively described (e.g., Sada and Nachlinger 1998, Sada et al. 2005, Fleishman et al. 2006), but the importance of relationships between physical and chemical characteristics (e.g., discharge, temperature, EC, dissolved oxygen, etc.) of springs is less certain. Regression analyses examining relationships between physical and chemical characteristics of LAME springs found some were statistically significant, but low correlation coefficients for each regression were very low. Similar results were found for JOTR springs, which suggest that relationships between physical and chemical characteristics are weak and poorly described by regression equations.

Two basic strategies have been suggested to manage arid land springs in the southwestern U.S. The U.S. Fish and Wildlife Service (1990), Hubbs (1995), Sada et al. (2001), and others (e.g., Burton and Metzinger 1994, Weldon 1996, Sada et al. 1998, Whiteman and Sites 2007) outlined strategies to protect springs with rare, crenobiontic species, and, for springs without crenobiontics, Myers and Resh (1999) and Sada et al. (2001) discussed the importance of managing for wildlife diversity by maintaining the functional characteristics of riparian and aquatic communities.

Past inventories and the 2007 spring surveys indicate that management and restoration of rare species are necessary at some LAME, springs while at others, it is more appropriate to focus on biodiversity (ergo as riparian communities and water sources for wildlife nesting, roosting, and feeding habitat). Neither of these strategies is important for springs that dry, flood, or are chemically harsh because their aquatic and riparian communities are highly tolerant and minimally affected by management or human activity. Managing for rare species and biodiversity are not mutually exclusive, since any management for rare species should also protect spring ecosystems and maximize biodiversity. In LAME, limiting management to springs occupied by rare species will include relatively few springs and therefore a limited amount of regional aquatic and riparian diversity. A more inclusive approach should focus on rare species and other springs with the greatest potential to support biodiversity. Informed

decisions regarding LAME spring management and restoration may be made by using the list shown in Table 3 where highest priority sites support rare species and springs with the highest amount of biodiversity

Rogers and Blue Point springs are high priority springs because of their size and concentration of rare species, and both of these springs have been more adversely affected by non-native aquatic species than other LAME springs. Deacon et al. (1964) and Hubbs and Deacon (1964) record the history of aquarium fishes introduced into Rogers Spring. Mosquito fish, convict cichlids, and the red-rimmed melania were more recently introduced into Blue Point Spring (Sada, field notes). It is likely that impoundment of Rogers Spring, which caused a functional shift from a flowing stream to a pond, and concomitant establishment of introduced aquarium fish caused the demise of its springsnail population. Surveys in Blue Point Spring by R. Hershler and D. Sada in the early 1990s recorded that the Blue Point pyrg springsnail (*Pyrgulopsis coloradensis*) and another springsnail (*Tryonia porrecta*) were uncommon. Cichlids were not recorded in this spring during the early 1990s surveys but subsequent surveys noted their presence and the apparent absence of springsnails (Hershler 1998, Sada, field notes). Extinction of these springsnail populations was recorded by Sada (2002) because they had not been seen for more than a decade, but they were rediscovered in 2007 in approximately 5 m of spring brook lying upstream from a USGS weir (Sada, field notes). Cichlids did not occupy the portion of spring brook when springsnails were rediscovered, which suggested that springsnail abundance may be influenced by the presence of fish. During a recent survey (summer 2008) fish had become established above the weir and springsnails could not be found, which provides additional evidence of detrimental impacts of these non-native fish on springsnail abundance. An undescribed amphibious mollusk (*Assimineia* sp.) that is closely related to the Badwater snail (*Assimineia infima*) was found at Blue Point Spring in 2006 (Sada, field notes). Its population appears to be stable.

The greatest management challenge for LAME springs is to restore degraded habitats, control invasive species, and prevent future habitat loss and establishment of non-native species. Restoration programs are needed to ameliorate the effects of human activities that have altered almost one-half of LAME springs, and to control salt cedar and its affect on spring-fed riparian communities. Non-native aquatic species should also be removed from Blue Point Spring to conserve molluscs that occur only in this spring. Future challenges for springs include introduction of the Quagga mussel (*Dreissena rostriformis bugensis*), which occurs in Lake Mead and the New Zealand mudsnail (*Potamopygrus antipodarum*) that is rapidly spreading through the western U.S. These introductions are most likely to occur at Rogers Spring by recreational bathing, and like past fish translocation, its introduction into nearby Blue Point Spring is likely. The presence of either species will alter functional characteristics of the aquatic system, which will adversely affect relict leopard populations and cause extinction of molluscs that are endemic to Blue Point Spring (and LAME). Spring discharge is also vulnerable to effects of groundwater pumping, particularly at springs that are supported by large aquifers that extend beyond LAME boundaries. Monitoring programs are needed to establish baseline conditions of spring environments and biota and to track changes in discharge, physical characteristics of the environment, and their biota. Management programs are needed to ensure that physicochemical changes in the environment and biota do not extirpate populations and alter natural functional characteristics of LAME springs.

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APPENDIX I. Level I Spring Inventory Data Elements

The following elements were recorded on data sheets.

- Date the survey is conducted. Record this in the 'month/day/year' format.
- Lead Person (Surveyor) conducting the spring survey by first letters of their given and middle names and surname (e.g., JDSmith).
- Field Note Number. Standardize the number by including the initials of the person recording data followed by the last two digits of the year the survey is conducted, then, after a hyphen, followed sequentially by the number of the spring that has been surveyed by the lead surveyor during the year (e.g., for the 21st and 22nd springs surveyed during the year 2003, JS03-21, JS03-22, etc.).
- The State where the spring is located. Record as the standardized abbreviation used by the U.S. Postal Service (e.g., CA = California, NV = Nevada).
- The County where the spring is located. This information is on maps, which can be reviewed in the office or the field.
- Locality, which is the spring name. If unnamed, record it as 'unnamed' with a brief geographical description of its approximate location, e.g., 'unnamed spring in Willow Canyon'.
- Location ID, which is an identification number for each spring within a National Park. Each Park has a standardized format for this number, such as LAME_SPINV_ONE_01.
- Drainage Basin where the spring is located. If the spring is located within a river drainage, list the river drainage basin. If it occurs in an endorheic basin, identify the valley. This information must be compiled from maps, and it may be done while in the field or in the office. This information is important because of its relevance to aquatic and semi-aquatic species that may occur at springs.
- Township, Range, and Quarter-section Coordinates. Record from USGS topographic maps.
- 1:100,000 scale USGS map that includes the spring/seep location. Finer scale maps may be used, but 1:100,000-scale maps have greater utility because they include a greater portion of the landscape and efficiently show the array of roads that provide access to sites.
- Global Positioning System (GPS) location, and the datum of the spring/seep source. Record the UTM zone in the North American Datum of 1983 (NAD83) unless otherwise specified. Document GPS files in a gps log. All geographic information system (GIS) data layers created from GPS files must include FGDC Geospatial and Biological Profile (NBII) compliant metadata. Record PDOP or '+' the number of meters as metrics indicating accuracy of the GPS reading.
- Access. Record the ease at which the public could visit a spring. Categories 1 through 5. Category 1 = inaccessible sites, access only by cross-country hiking; Category 2 = sites that can be accessed only by arduous trail hike (e.g., > 5 miles); Category 3 = sites accessed by easy trail hike (e.g., 1 to 5 miles) and four-wheel drive vehicle; Category 4

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= sites easily accessed by walking less than 1 mile or a two-wheel drive, high clearance vehicle; and Category 5 = sites immediately adjacent to high-quality gravel road or a paved road.

- Photos. These photos should be taken to show the spring and its landscape context. One should overview the spring source and looking downstream, and the second from the spring brook's end looking upstream. At larger springs, take one photo of the source and a second from a distant area that encompasses as much of the riparian area as possible. Photos should be labeled by site ID number, date, site name, Township, Range, quarter-Section location, and GPS coordinates of the point where the photo was taken. Photos should be taken using a digital camera. Maintain a photo log with digital photograph number and description using the Location ID. Note on the field form that photos were taken.
- Spring elevation, in meters using a Thommen hand-held meter, GPS system, or interpolated from a USGS topo map. There may be substantial error in all of these measurements, but these data are adequate to 'characterize' site elevation. For more accurate elevations, estimate them from a 10-m Digital Elevation Model. Record methods used for elevation in notes section.
- Land ownership, as U.S. National Park Service, U.S. Forest Service, U.S. Bureau of Land Management (BLM), tribal, military, private, or other (e.g., State lands, U.S. Fish and Wildlife Service, municipality, etc., write out the name of the owner). This information is most easily determined using BLM Surface Management Maps (1:100,000 scale).
- 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 defined channel), **Helocrene** (similar to a Limnocrene, but marshy and comparatively shallow, not an open pond or pool), or unknown. In some areas, springs have been altered by native peoples or settlers by excavating the source to create a **Qanat**, which is a type of hand-dug well. Where these occur, water is regionally scarce and where surface water is scarce. Also record if a site is a mechanically dug **Well** (usually with rock, metal, or plastic casing). Record **Other** when the source is something else, such as a cliff face, boil, etc. Record spring type as **Unknown** at highly disturbed sites where no semblance of natural characteristics of a spring remains, or where the spring is dry. Examples of disturbances that prevent identifying spring type include impoundment by dikes, sources in a spring box, or dredging and filling to capture water in a pipe leading to a trough. Spring alterations and spring condition are assessed, and recorded, in the Site Condition section below. If further description is necessary, it can be summarized in the Notes Section.
- Spring Discharge, estimated in liters/minute. It is difficult to estimate the discharge of most arid land springs because they are small, water is usually shallow and broadly and unevenly spread over a wide area, and areas with moving water are often very limited. Accuracy is also a relative term because discharge often changes throughout the day, seasonally, or annually, which minimizes the effectiveness of single measurements to precisely quantify long-term discharge characteristics. Highly quantitative discharge recording is a component of Level III surveys.

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- Preferably For Level I surveys, measure discharge by recording the length of time required to fill a container with a known volume. Unfortunately, it is usually not possible to use this method because most arid land springs are very small and it is difficult to capture water in a container (their small size also prevents using a water current velocity meter to measure discharge). While these factors limit the precision of most discharge estimates, the amount of water issuing from spring sources should be estimated in liters/minute. These estimates combined with water width, depth, and spring brook length provide sufficient information to characterize spring discharge rates.
- Spring Brook Length, measured in meters. Use a tape to measure distance from the spring source (upstream limit of surface water) to the downstream limit of surface water.
- Average Water Depth. This is a qualitative estimate of the vertical distance from substrate to water surface (in centimeters) that is found throughout the aquatic habitat.
- Estimate the average Water Width. This is a qualitative estimate of the distance covered by water (and perpendicular to its flow) that lies between banks of the spring brook, less islands, emergent rocks, etc., in centimeters. (This is formally described as the length of wetted contact between flowing or standing water and the spring brook bank in a vertical plane at right angles to the direction of flow.)
- Dissolved Oxygen Concentration, (D.O., in mg/liter) using a field meter (e.g., YSY, Oakton, etc.). The meter should be kept clean, have fresh batteries, and calibrated daily following the manufacture's recommendation. All water chemistry 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.
- Water Temperature. Water temperature is an important factor structuring aquatic communities, and may give insight into source waters. This measurement (record in degrees Centigrade) is easily taken with a meter used to measure dissolved oxygen or conductivity, and it is necessary to calibrate some analytical meters (e.g., conductivity). Field measurements can be easily made using a high quality meter. Calibration is not necessary for temperature measurements using a high quality meter.
- Conductivity (also called electrical conductance). Conductivity is a measurement of the ability of an aqueous solution to carry an electrical current. This ability is dependent on the amount of dissolved ions, and is therefore an indicator of total dissolved solids in the solution. Conductivity provides insight into water sources and it is important to aquatic life because of requirements to maintain osmoregulatory balance. Conductivity is measured using a field meter (e.g., YSY Model 30, Oakton Acorn CON 5, etc.) and recorded in mhos, μ mhos, or microsiemens. The meter should be kept clean, have fresh batteries, and calibrated daily following the manufacturer's recommendation. Most high-quality meters do not require frequent calibration. Salinity may also be measured, but the greatest amount of information regarding a spring's ability to conduct an electrical current is provided by measuring conductance.
- pH. pH is the measure of hydrogen activity, which indicates the acid/basic qualities of water. It can be measured using a hand-held field meter that can be calibrated (such as

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Oakton Model, pHtestr2). Low (<6.5) and high (>8.0) pH environments are stressful to aquatic life. The meter should be kept clean, have fresh batteries, and calibrated daily following the manufacturer's recommendation. These meters generally have a limited life, and a backup meter should always be carried.

- Emergent Cover. Estimate to the nearest 10 percent the vegetative, debris, or other material that arises within the water width and covers the water surface.
- Vegetative Bank Cover. Estimate to the nearest 10 percent the proportion of spring brook banks that is covered by live vegetation.
- Substrate Composition. Qualitatively estimate 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.
- Important animals and plants. Note the presence of important animal (see Tables 1 & 2, & Appendix IV) and plant species. Important species are those that occupy or use the aquatic or riparian environments, and noted during the survey. This list may differ among management areas, and it should be compiled accordingly. It should include: 1) rare species (crenobiontics, amphibians, bats, birds, mammals, etc.), 2) species that are indicative of spring characteristics (e.g., species of woody vegetation, obligatory and facultative wetland vegetation, crenobiontics), and 3) non-native species. Species should be identified, if possible (many surveyors will be unable to identify species). If a species cannot be identified, the presence of plants and animals within any of the important groups should be recorded (e.g., native fish and trees, mollusks, aquatic insects, non-native species, etc.). Also note the presence of important terrestrial species, such as bats, if seen. Noting the presence of these types of species provides information that assists with identifying management issues and can be used to determine management priorities.

Important species occupy a wide variety of habitats, and they may be very scarce or abundant. Most aquatic macroinvertebrates can be readily captured with a kitchen sieve (~ 1 mm mesh) that is used to collect animals from aquatic vegetation, debris, or substrate. Each species prefers a distinct microhabitat, and sampling must include all habitat types that occur in a spring (e.g., sand, gravel, & cobble substrates, all types of emergent and submerged vegetation, all current velocities, mid-channel, backwater, and lateral habitats). Crenobiontic macroinvertebrates are generally common in specific habitats, but they may be scarce remaining areas within the aquatic system. Time required to survey for crenobiontics varies with spring size, but crenobiontic surveys should focus on upstream reaches of a spring brook because crenobiontic abundance decreases downstream. Large springs usually require more sampling than small springs because they support a greater diversity of aquatic habitat types. In small springs (spring brook < 100 m long), sample for a minimum of 15 minutes, in larger springs sample for a minimum of 25 minutes. Create a list of important plant and animal species that are likely to occur within a survey area on the Level I survey form.

Appendix I.

- Important native plant species. Note the presence of important native plant species (e.g., rushes [Family Juncaceae], cattails [*Typha* sp.], reeds [*Scirpus* sp.], watercress [*Rorippa* sp.], spikerush (*Eleocharis* sp.), sedges [*Carex* sp.], yerba mansa (*Anemopsis californica*), mesquite (*Prosopis* sp.), wild rose (*Rosa* sp.), cottonwood (*Populus freemontii*), willow (*Salix* sp.), or other large woody vegetation in spring brook or riparian zone. Identify if possible; most species will be willow, cottonwood, mesquite, spikerush, or rushes. Circle species on the list provided on the survey form. Modify the list to include taxa that the management believes are important, if necessary.
- Important native animals. Note the presence of important native animal species (e.g., crenobiontics, amphibians, fishes, ostracodes, amphipods, finger clams, etc.).
- Important non-native plants and animals. Note the presence of non-native species (Table 2). Non-native plants that most likely occur at arid land springs include salt cedar (*Tamarisk* sp.), palm trees (Family Arecaceae), arundo (*Arundo donax*), and white top (*Cardaria pubescens*). The most likely non-native animals include mosquito fish (*Gambusia affinis*), bass (*Micropterus* sp.), trout, crayfish, and red-rimmed melania (*Melanoides tuberculata*).
- Site Condition. This evaluation qualitatively identifies 1) disturbance factors stressing a spring and 2) the amount of stress of each factor on the spring environment. Harsh chemical conditions are not noted in this section, but can be easily determined from water quality and conductance measurements. Determine factors causing stress by looking for evidence of natural and human caused disturbances. Influences of flooding are indicated by location of a spring in the bottom of a gully, presence of a naturally incised channel, and usually a paucity of vegetation. The presence of pipes, dikes, or spring box indicates modifications for diversion. Abundance of hoof prints and droppings, and evidence of grazing indicates ungulate use of a spring. The presence of campsites and trash indicates recreation. The most common stressing factors are listed on the field form, and the appropriate factor(s) affecting a spring should be circled. Disturbance may be influenced by multiple factors such as trampling by intensive livestock and diversion into a trough; recreation use along a spring brook that tramples vegetation and the spring brook is channelized away from areas used for picnicking. Circle each appropriate factor. If other factors are evident, circle Other and briefly describe in the Notes Section.
- Categorize each spring as undisturbed, slightly, moderately, or highly disturbed, and circle the appropriate category on the survey form. When entering data into a database, identify these categories as: 1 = undisturbed, 2 = slightly disturbed, 3 = moderately disturbed, and 4 = highly disturbed for easier data analysis. Springs with these levels of disturbance appear as:
 - Undisturbed springs have been unaffected by recent or historical factors or activities. All evidence of trampling, diversion, fire, or drying is absent. Since most springs have been altered by humans, drought, fire, or flood, these types of springs are rare and most undisturbed springs are naturalizing from past disturbances.

Appendix I.

- **Slightly Disturbed** springs exhibit little evidence that vegetation or soil have been disturbed. Vegetation shows slight signs of browsing and foraging, and animal footprints and scat are present but not prominent. Recreation may be evident, but its impact on riparian or aquatic environments is minimal. Evidence of fire or flooding in the distant past may be visible but these events occur infrequently; riparian vegetation is vigorous.
- **Moderately Disturbed** springs exhibit evidence of recent, comparatively high disturbance. Use by native and non-native ungulates, and recreation has reduced vegetation height and coverage from natural conditions. Vegetation covers, hoof prints, footprints, and scat are common. Where there has been diversion, a spring box may be present but at least 50% of natural discharge remains within the natural spring brook. Neither the spring nor spring brook has been impounded. Where flooding or fire is apparent, > 50% of the spring brook banks are covered by vegetation; flood and fire are infrequent and the spring is naturalizing.
- **Highly Disturbed** springs have little similarity to undisturbed springs. Less than 50% of their banks are covered by vegetation, their spring brooks contain < 50% of natural discharge, they are impounded or dredged, or spring boxes collect water. All impounded springs are highly disturbed because flow has been interrupted and functional characteristics of the aquatic system have been highly altered. Hoof prints and scat are abundant where ungulate use is heavy, and campsites are large, trashy, and vehicle use evident. These activities have decreased vegetative cover of spring brook banks to < 50%. Springs affected by drought (springs that are dry when sampled or experience seasonal or annual drying) should also be categorized as highly disturbed. These springs can be identified by the presence of upland riparian species and absence of obligatory wetland plants. Riparian vegetation is sparse at springs recently affected by fire or flooding, there is recent evidence of elevated discharge, and spring brooks are usually incised.
- **Notes**, to include additional pertinent information. This may include observations further describing site condition, use of the spring by other animals (e.g., bats, wild horses, etc.), clarification of difficulties in accessing the spring, etc.
- **Sketch**, of the spring if necessary. This may be very important in spring provinces where sample sites may be close to one another and map/GPS coordinates weakly describe the relative location of sample sites.

Appendix II.

APPENDIX II. Level I Spring Inventory Audit Form

National Park Service - Mojave Inventory and Monitoring Network

Auditors and Field Crew

Date: _____
Field Note No.: _____
Crew Leader: _____
Crew Member(s): _____
Auditor(s): _____

General

Crew operates safely / follows safety measures	Yes	No
Crew uses and maintains equipment properly	Yes	No
Crew communicates effectively with each other	Yes	No
Crew uses time efficiently	Yes	No
Crew uses written protocols to solve problems	Yes	No

Level I Data Elements

Field Note Number

1. Did the crew use the correct format for the field note number?	Yes	No
2. Did crew 1 use numbers 1-250 and/or crew 2 use numbers 251 – 500?	Yes	No
3. If site was a spring province, were all springs identified?	Yes	No
4. If site was a spring province, were all springs numbered correctly?	Yes	No

Lead Person (Surveyor)

5. Was the lead surveyor name described correctly (e.g., JDSmith)?	Yes	No
--	-----	----

Date and Time

6. Was a correct EventID entered (e.g. SPINV_ONE_20040108_1100)?	Yes	No
--	-----	----

State, County, and Locality

7. Were the state, county and locality entered correctly on the data sheet?	Yes	No
---	-----	----

Location ID

8. Was a correct LocationID entered on the data sheet? (e.g. LAME_SPINV_ONE_0001)	Yes	No
---	-----	----

Drainage Basin

9. Was the drainage basin correctly identified by the field crew?	Yes	No
10. If it was an endorheic basin (ergo enclosed), did they identify the valley?	Yes	No

Township, Range, and Quarter-Section Coordinates, USGS Map

11. Were the T/R/¼S correctly identified from the USGS topographic maps?	Yes	No
12. Was the name of the USGS map correctly identified?	Yes	No

Appendix II.

GPS location and datum

- | | | |
|--|-----|----|
| 13. Did the crew use the NAD83 datum? | Yes | No |
| 14. Were the GPS coordinates correctly transferred from the GPS meter? | Yes | No |
| 15. Did the crews record the PDOP? | Yes | No |

Access

- | | | |
|---|-----|----|
| 16. Do the crews understand the access categories? | Yes | No |
| 17. Did they select the correct category for this spring? | Yes | No |

Spring elevation

- | | | |
|--|-----|----|
| 18. Did the crew accurately describe the elevation of the spring? | Yes | No |
| 19. Did they record the method used to determine elevation in the notes section? | Yes | No |

Photos

- | | | |
|---|-----|----|
| 20. Did the crews select the most appropriate locations for the photos? | Yes | No |
| 21. Were the photos described in a photo log? | Yes | No |

Land ownership

- | | | |
|---|-----|----|
| 22. Did the crew record the correct land ownership (National Park Service)? | Yes | No |
|---|-----|----|

Spring Type:

- | | | |
|--|-----|----|
| 23. Did the crew demonstrate an understanding the how to distinguish the differences between a rheocrene, limnocrene, or helocrene spring types? | Yes | No |
| 24. If the spring had been dug out, was it described correctly? | Yes | No |

Spring Discharge

- | | | |
|---|-----|----|
| 25. Was the crew's estimate for spring discharge (in liters/minute) acceptable? | Yes | No |
| 26. Did the crew use appropriate means for estimating the discharge? | Yes | No |

Spring Brook Length

- | | | |
|--|-----|----|
| 27. Did the crew select the correct starting and ending points for the measurement of spring brook length? | Yes | No |
| 28. Was the measurement made in a straight line? | Yes | No |
| 29. If springs in a spring province joined, were the correct locations chosen for ending points? | Yes | No |
| 30. Do crews know what to do if the spring begins as a pipe or trough? | Yes | No |

Average Water Depth and Width

- | | | |
|--|-----|----|
| 31. Was the average water depth and width estimated at the source? | Yes | No |
| 32. Were these measurements made in centimeters? | Yes | No |

Dissolved Oxygen Concentration

- | | | |
|---|-----|----|
| 33. Was the DO meter clean, with fresh batteries, and calibrated? | Yes | No |
| 34. Was the DO measured as close to the spring source as possible? | Yes | No |
| 35. Was the DO probe submerged and in flowing water? | Yes | No |
| 36. Does the crew understand how to address difficult situations (pipes, helocrenes, etc.)? | Yes | No |
| 37. If DO measurements could not be taken at the source, was this noted? | Yes | No |

Water Temperature

- | | | |
|---|-----|----|
| 38. Was sufficient time allowed for an accurate reading of temperature? | Yes | No |
| 39. Was the temperature probe submerged and in flowing water? | Yes | No |

Appendix II.

Conductivity

- | | | |
|---|-----|----|
| 40. Was the conductivity meter clean, with fresh batteries, and calibrated? | Yes | No |
| 41. Was the conductivity probe submerged and in flowing water? | Yes | No |
| 42. If the salinity exceeds the meter's calibration, does the crew know what to do? | Yes | No |

pH

- | | | |
|---|-----|----|
| 43. Was the pH meter clean, with fresh batteries, and calibrated? | Yes | No |
| 44. Does the crew have a backup pH meter? | Yes | No |
| 45. Was the pH probe submerged and in flowing water? | Yes | No |

Percent of Emergent Cover

- | | | |
|---|-----|----|
| 46. Was the crew's estimate of emergent cover acceptable? | Yes | No |
|---|-----|----|

Percent of Vegetative Bank Cover

- | | | |
|---|-----|----|
| 47. Was the crew's estimate of vegetative cover acceptable? | Yes | No |
|---|-----|----|

Substrate Composition

- | | | |
|---|-----|----|
| 48. Does the crew understand the size differences between fines, sand, gravel, cobble, boulder and bedrock? | Yes | No |
| 49. Was the crew's estimate of the substrate composition taken near the spring source? | Yes | No |
| 50. Was the crew's estimate of the components of the substrate composition acceptable? | Yes | No |
| 51. Does the total composition add up to 100%? | Yes | No |

Important groups of animals

- | | | |
|---|-----|----|
| 52. Did the crew use correct procedures when searching for species? | Yes | No |
| 53. Did the crew correctly identify the presence and abundance of important groups of spring animals (e.g.- ergo springsnails, amphipods, fish, clams, and amphibians)? | Yes | No |
| 54. Did the crew clean and dry the sampling equipment to prevent spreading biota from one spring to another? | Yes | No |

Trees or large woody vegetation

- | | | |
|---|-----|----|
| 55. Did the crew note the presence trees and large woody vegetation? | Yes | No |
| 56. Were the species or common names correctly identified in the notes section? | Yes | No |

Non-native species

- | | | |
|---|-----|----|
| 57. Did the crew note the presence of non-native species?
(e.g. - salt cedar, palm trees, mosquito fish, bass, and arundo) | Yes | No |
| 58. Were the non-native species correctly identified in the notes section? | Yes | No |

Site Condition

- | | | |
|--|-----|----|
| 59. Does the crew understand the differences between the various spring site conditions?
(undisturbed, slightly disturbed, moderately disturbed, or highly disturbed) | Yes | No |
| 60. Was the site condition correctly described? | Yes | No |

Disturbance factors

- | | | |
|--|-----|----|
| 61. Were all disturbance factors correctly identified? | Yes | No |
|--|-----|----|

Notes

- | | | |
|--|-----|----|
| 62. Were the crews careful to include additional important information in the notes? | Yes | No |
| 63. Did the crews prepare a map of the spring(s)? | Yes | No |
| 64. Was the field note number written on the map? | Yes | No |

Appendix II.

Comments

Appendix III.

APPENDIX III. List of LAME Springs Visited during 2007

The list shows the number for each spring on Figure 1 (No.), field note number (FNN), site name (NAME), spring type (TYPE), UTM's (Northing and Easting coordinates), estimated spring brook length (meters; LGTH), water temperature (degrees Celsius; °C), electrical conductance (µmhos; EC), the number of native woody species of vegetation (either one or a combination of cottonwood, mesquite, or willow) at the spring (VEG), whether or not the spring dries (DRY) or is affected by scouring floods (FLO), and the type and level of human disturbance (DIST). Too little water indicates springs with insufficient water to collect water chemistry information. Types of human disturbance are coded as R—recreation, D—diversion, DR—dredging, U—non-native ungulates (burros), and the level of human disturbance is categorized as 2 for slight, 3 for moderate, and 4 for high disturbance (see Appendix I for description of disturbance categories). Blank cells in the human disturbance column indicate the spring was not disturbed by human activity.

Appendix III.

No .	FNN	Name	Type	Northing	Easting	DISH	SBL	°C	EC	Dries	Floods	Human
1	CJ06-212	Kelsey Spring	Rheocrene	4045695	731429	1	40	6.0	4410	yes	no	
2	CJ06-209	Getchel Spring	Rheocrene	4036188	732555	1	90	8.8	25490	no	yes	D2
3	CJ06-213	Valley of Fire Upper Spring	Rheocrene	4032192	730382	6	1000	11.9	129500	no	yes	R3:U2
4	CJ06-228	Valley of Fire Wash Lower Spring	Rheocrene	4031571	733010	20	400	22.9	6120	no	yes	U2
5	CJ06-214	Blue Point Spring	Unknown	4030200	730235	500	3500	29.5	4170	no	no	R2:DR4:U2
6	CJ06-224	Gnatcatcher Spring	Rheocrene	4029491	730172	25	100	14.0	4367	yes	yes	U2
7	CJ06-225	Mead Valley Spring	Dry	4029147	731019					yes	no	
8	CJ06-215	Scirpus Spring	Rheocrene	4028555	728877	5	250	24.1	3935	no	no	U2
9	CJ06-216	Scirpus Spring Unnamed	Dry	4028637	728964					yes	no	
10	CJ06-217	Rogers Spring	Unknown	4028886	729295	1000	3000	29.8	3736	no	no	R2:D4:DR4:U2
11	CJ06-218	Corral Spring	Unknown	4028065	727863	3	20	23.3	3890	yes	no	DR3:U2
12	CJ06-219	Corral Spring Unnamed	Dry	4028252	728232					yes	no	
13	CJ06-226	Rogers Wash Spring Unnamed	Dry	4028098	729955					yes	no	
14	CJ06-227	Rogers Bay Spring Unnamed	Rheocrene	4026624	730032	5	60	16.5	5840	no	yes	U2
15	CJ06-220	Calico Bay North Spring Unnamed	Dry	4023361	729966					yes	yes	
16	CJ06-221	Calico Bay Middle Spring Unnamed	Dry	4023177	730119					yes	yes	
17	CJ06-222	Calico Bay South Spring Unnamed	Dry	4022798	730192					yes	yes	
18	CJ06-223	Bitter Spring	Rheocrene	4018452	723290	10	500	17.4	3975	no	yes	R4
19	CJ06-259	Sandstone Spring	Limnocrene	4010100	719691	1	1	9.9	1466	yes	yes	D3
20	CJ06-260	Cottonwood Spring	Rheocrene	4009005	711866	1	1	10.6	3865	no	yes	R3
21	CJ06-208	Cottonwood East Spring	Rheocrene	4009039	758676	4	70	18.0	1270	no	yes	U2
22	CJ06-203	Grapevine Wash Spring 2 Unnamed	Dry	3994350	768801					yes	no	
23	CJ06-204	Grapevine Wash Spring 1 Unnamed	Dry	3994283	768795					yes	no	
24	CJ06-205	Grapevine Wash Spring	Rheocrene	3994208	768817	3	20	12.1	911	no	no	R2
25	CJ06-206	Grapevine Spring AZ	Rheocrene	3992987	767934	500	1100	12.4	785	no	no	R2:D2
26	CJ06-202	Granite Cove Spring Unnamed	Rheocrene	3988897	756896	4	10	19.7	3103	no	no	U3
27	CJ06-201	Burro Spring LAME	Rheocrene	3989047	755577	12	30	17.2	3172	no	no	U3
28	CJ06-193	Salt Spring	Rheocrene	3986156	747320	50	20	13.6	4065	no	no	D2

Appendix III.

No.	FNN	Name	Type	Northing	Easting	DISH	SBL	°C	EC	Dries	Floods	Human
28	CJ06-193	Salt Spring	Rheocrene	3986156	747320	50	20	13.6	4065	no	no	D2
29	CJ06-194	Salt Spring Bay 2 Unnamed	Dry	3986618	748274					yes	no	
30	CJ06-195	Salt Spring Bay 1 Unnamed	Rheocrene	3986638	748220	1	50	13.0	3754	yes	no	
31	CJ06-196	Quail Spring East	Rheocrene	3986750	748008	1	10	13.2	6140	yes	no	
32	CJ06-197	Salt Seep 3 Unnamed	Rheocrene	3986532	747789	5	80	18.7	4051	yes	yes	
33	CJ06-198	Salt Seep 2 Unnamed	Dry	3986606	747685					yes	no	
34	CJ06-199	Salt Seep 1 Unnamed	Dry	3986593	747588					yes	no	
35	CJ06-200	Salt Seep 4 Unnamed	Dry	3986402	747295					yes	no	
36	CJ06-192	Monkey Cove Spring	Rheocrene	3991780	740354	50	50	13.0	1613	no	no	
37	CJ07-001	Horsethief Canyon	Rheocrene	3986425	713409	8	700	11.8	963	no	yes	
38	CJ06-231	Pupfish Cold Spring	Unknown	3987394	703233	4	125	22.0	1245	no	yes	R2:D4
39	CJ06-230	Pupfish Hot Spring	Unknown	3987193	703312	150	125	31.5	1200	no	yes	R2:D4
40	CJ06-261	Gold Strike Nevada Hot Spring Upper	Rheocrene	3986599	702846	500	1000	48.7	1640	no	yes	R4:D4:DR3
41	CJ06-262	Gold Strike Canyon Upper	Rheocrene	3986590	702726	2	2	22.3	736	no	yes	R3
42	CJ06-229	Sauna Cave	Unknown	3986643	703397	60	70	42.6	1640	no	no	R3:D2
43	CJ06-232	Vaghini Spring	Other	3986533	703452	2	1	47.9	1791	no	yes	
44	CJ06-233	Jacobs Spring	Other	3986590	703396	6	10	33.4	1551	no	yes	
45	CJ06-236	Arizona Hot Spot 2	Dry	3986630	703479					yes	no	
46	CJ06-238	Arizona Hot Spot 1	Rheocrene	3986430	703607	10	25	54.1	3435	no	yes	D2
47	CJ06-237	Hot Spring 1 Unnamed	Dry	3986394	703702					yes	no	
48	CJ06-263	Sugarloaf Spring	Rheocrene	3986571	703986	10	150	20.1	2523	no	yes	
49	CJ06-264	Sugarloaf Seep	Seep	3986730	704257	1	Too little H2O			yes	yes	
50	CJ06-234	Nevada Hot Spot	Rheocrene	3986318	703467	200	10	60.7	2126	no	no	R2
51	CJ06-235	Gold Strike Nevada Hot Spring Lower	Other	3986278	703345	60	3	57.0	2090	no	no	R3
52	CJ06-239	Hot Spring 2 Unnamed	Unknown	3986240	703691	12	100	31.6	4160	no	no	D2
53	CJ06-241	Palm Tree Hot Spring A	Rheocrene	3985770	703869	20	100	54.8	3366	no	yes	R2:D2
54	CJ06-242	Palm Tree Hot Spring B	Rheocrene	3985775	703816	5	50	46.7	3437	no	no	R2:D3
55	CJ06-240	Palm Tree Cold Spring	Rheocrene	3985701	703985	4	200	12.4	7200	no	yes	
56	CJ06-243	Dawn Hot Spring	Other	3985033	703288	100	75	44.3	4650	no	yes	
57	CJ06-244	Dawn Cold Spring	Unknown	3985033	703288	100	75	16.9	4107	no	yes	
58	CJ06-245	Lost Man Hot Spring	Unknown	3984680	703582					no	yes	
59	CJ06-247	Boy Scout Hot Spring	Rheocrene	3984423	702943	600	1000	48.0	4100	no	yes	R3
60	CJ06-248	Boy Scout Cold Spring	Unknown	3984474	703022	12	70	21.6	4099	no	no	

Appendix III.

No.	FNN	Name	Type	Northing	Easting	DISH	SBL	°C	EC	Dries	Floods	Human
61	CJ06-246	Boy Scout Cavern Spring	Other	3984465	703400	<.5	Too little H2O			yes	no	
62	CJ06-249	Salt Cedar Hot Spring	Unknown	3982452	703483	500	750	33.1	4680	no	yes	
63	CJ06-250	Salt Cedar 2 Spring (Cold)	Unknown	3982221	703638	15	150	9.4	4520	no	yes	
64	CJ06-252	Arizona Hot Spring	Rheocrene	3981996	704108	80	200	46.0	4253	no	yes	R4:D4
65	CJ06-251	White Rock Canyon	Seep	3982486	705049	<.5	Too little H2O			no	yes	R3
66	CJ06-253	Black Canyon Spring 2 Unnamed	Rheocrene	3981988	705189	4	10	19.0	2950	no	yes	R3
67	CJ06-254	Nevada Falls	Unknown	3980368	704596	12	50	14.9	1005	no	no	
68	CJ06-255	Nevada Hot Spring Unnamed	Seep	3980195	704533	<.5	Too little H2O			yes	no	
69	CJ06-256	Bighorn Sheep Spring	Unknown	3979574	704388	5	200	11.1	695	no	yes	
70	CJ06-257	Black Canyon Spring 3 Unnamed	Seep	3979515	705536	<.5	Too little H2O			yes	no	
71	CJ06-258	Arizona Seep	Seep	3978430	706935	<.5	Too little H2O			yes	no	
72	RV06-045	Latos Pools	Rheocrene	3969572	705098	4	30	13.1	267	no	yes	
73	CJ06-211	Aztec Spring	Rheocrene	3948480	701726	10	120	18.7	1922	no	yes	D3
74	CJ06-189	South Pipe Spring	Rheocrene	3906665	712044	1	10	14.4	1492	no	yes	
75	CJ06-190	Pipe Spring	Rheocrene	3906748	711403	4	15	17.8	1492	no	no	D2
76	CJ06-191	Rattlesnake Spring	Dry	3902873	706740					yes	no	
77	CJ06-188	Willow Spring	Rheocrene	3903487	708359	2	8	14.5	1023	no	no	D2
78	CJ06-187	Discovery Spring	Dry	3903990	710380					yes	yes	R2:D3
79	CJ06-210	Sacatone Spring Unnamed	Rheocrene	3902993	709832	1	Too little H2O			yes	yes	
80	CJ06-186	Sacatone Spring	Rheocrene	3902306	711088	1	3	9.7	1042	yes	no	
81	CJ06-185	Sacatone Spring Main (Lower)	Rheocrene	3902299	711802	5	110	18.9	1152	no	no	
82	CJ06-184	Grapevine Spring NV	Rheocrene	3900612	712127	2	150	20.7	1015	no	no	
83	CJ06-182	Moss Spring	Rheocrene	3900754	709829	1	1	20.2	829	no	no	R2
84	CJ06-183	Grapevine Canyon Spring	Rheocrene	3900704	710294	5	100	17.7	950	no	no	R2:D2
85	CJ06-179	Pipe Springs Canyon Unnamed Spring	Rheocrene	3898737	710782	3	50	18.7	1198	no	yes	D2
86	CJ06-181	Dripping Spring	Rheocrene	3897899	710836	2	30	20.3	1269	no	no	D2
87	CJ06-180	Dripping Canyon Upper Unnamed Spring	Rheocrene	3898266	710335	1	Too little H2O			yes	no	
88	CJ06-177	Bridge Canyon Spring	Rheocrene	3897490	707283	1	1	13.1	1049	yes	yes	
89	CJ06-178	Bridge Canyon Lower Spring Unnamed	Rheocrene	3896426	711127	3	20	15.7	1109	yes	yes	