



Inventory of Arivaca Cienega at Buenos Aires National Wildlife Refuge, Arizona

Physical and Biological Characteristics

Natural Resource Technical Report NPS/CHDN/NRTR—2013/818



ON THE COVER

View over the southeast portion of the Arivaca Cienega, Buenos Aires National Wildlife Refuge
Photograph: NPS

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Executive Summary

This report summarizes information gathered during an inventory of Arivaca Cienega conducted in 2011. The inventory was conducted as part of a cooperative effort between the Inventory and Monitoring Programs of the U.S. Fish and Wildlife Service and the National Park Service. The purpose of the inventory was to provide a consistent base level of information on springs across refuges and parks and to provide information to develop a strategy for long-term monitoring.

Although Arivaca Cienega has been significantly altered by humans in the past, it seems to have largely recovered from the disturbance, as evidenced by the dense riparian vegetation. Vegetation is dominated by facultative and obligate wetland species, such as cattails, rushes, willows, and cottonwoods. Several non-native species were found, including Bermuda grass, Johnson grass, Russian thistle, and ragweed.

Water quality characteristics were all within expected values. Patterns in water quality parameters were based on the direction of flow. Water temperatures were generally cooler near water sources and warmer as water moved away from these orifices. Similarly, pH and conductivity increased with distance from the orifices. Other water quality variables related to alkalinity and salinity were also measured. None exceeded expected values or standards set by Arizona Department of Environmental Quality or the U.S. Environmental Protection Agency.

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Introduction

Water in the Buenos Aires National Wildlife Refuge comes from seasonal runoff, thundershowers, and aquifers that support springs such as the Arivaca Cienega. Runoff and thundershowers often produce scouring flows that quickly pass through ephemeral streams, and springs often provide the only persistent, reliable water for humans and wildlife. Springs support aquatic and riparian systems where groundwater reaches the land surface through natural processes. They provide much of the aquatic environment in arid lands as well as a substantial portion of regional aquatic and riparian biodiversity. Springs and their related ecosystems are considered to be of high priority for providing goods and services to wildlife.

Spring ecosystems are small, relatively rare “biodiversity hot spots” in arid lands. In the desert southwest, these ecosystems historically supported a substantial proportion of aquatic, riparian, and terrestrial species (Myers and Resh 1999). About 80% of the terrestrial animal species, including two-thirds of non-game bird species use riparian systems associated with springs (Thomas et al. 1979, Saab et al. 1995, Brussard et al. 1998). Springs in arid lands are sparsely distributed on the landscape and critical to the persistence of native biota and many endemic species. Thus, the ecological importance of springs is disproportionate to their spatial extent (Schmitz et al. 2007). As a consequence of their lengthy isolation and long-term persistence, many arid-land springs support an endemic, obligate-spring-dwelling fauna and flora. Several hundred endemic aquatic and riparian species and subspecies dwell in spring ecosystems in the U.S. (Minckley et al. 1986, Hershler et al. 2002).

When they are persistent, springs are generally more stable than arid-land rivers or streams, because seasonal variability in temperature and discharge is much less in springs. Arid-land springs are distinct from springs in more mesic regions because arid-land springs are typically isolated from other waters and more susceptible

to drought. Aquifers in these arid regions are strongly influenced by high elevations, rugged topography, and diverse geology. Characteristics of each aquifer are influenced most by climate, geology, and topography (Freeze and Cherry 1979). In springs unaffected by human activity, water chemistry, temperature, spring morphology, 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).

Natural and human stressors similarly influence the structure of aquatic and riparian communities. Springs with high water temperature, high chemical concentrations, or that are disturbed by natural events (drought, fire, flood, avalanche scouring, etc.) and humans (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 by human or natural stressors. The influence of stressors on aquatic and riparian communities generally varies along a gradient of increasing frequency, duration, and magnitude of stressors. Biological communities of springs respond to stressing factors similar to other aquatic and riparian systems (e.g., Resh et al. 1988, Smith et al. 1991, Stromberg and Patton 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 colonization. As harshness increases, aquatic communities become less speciose, support fewer environmentally intolerant species (e.g., non-baetid mayflies, caddisflies), and become 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).

Surface-water dynamics and water chemistry have strong effects on aquatic biota; therefore, biological assemblages (e.g. aquatic macroinvertebrates) are often excellent indicators of flow regime, water chemistry, and disturbance history. Alteration of surface-water resources within desert ecosystems has profound ecological and management implications, including loss of species diversity, extinction or extirpation of special-status and endemic species, alteration in the composition and distribution of plant and animal communities, alteration of culturally significant sites, and inability of parks to meet legal and policy mandates.

Discharge rates, aquifer sources, and the presence of rare species (e.g., fishes, aquatic macroinvertebrates, rare plants, etc.) are

known for a number of large springs in arid regions of the western U.S., 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 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).

The purpose of this inventory is to provide a consistent, base level of information on springs across several U.S. Fish and Wildlife Service (USFWS) refuges and National Park Service (NPS) parks and to provide information to develop a strategy for long-term monitoring.

Methods

The Arivaca Cienega in Buenos Aires NWR was inventoried in early October 2011 following the Level 1 procedures described by Sada and Pohlmann (2006; located on enclosed CD). Arivaca Cienega was selected for inclusion in the inventory by USFWS staff led by Steve Cullinan.

The foundation for the protocol developed by Sada and Pohlmann (2006) is a number of hydrological and biological studies of springs in the western U.S. and elsewhere (e.g., Ferrington 1995, Botosaneau 1998, Meffe and Marsh 1983, Williams and Danks 1991, Thomas et al. 1996, Sada et al. 2005, and many others cited herein) that examined spring physicochemical conditions and their influence on spring-fed aquatic and riparian communities. The Sada and Pohlmann (2006) protocol contains two levels of field procedures. The level of the Sada and Pohlmann (2006) protocol conducted at each spring depends on the amount of spring flow. The Level I procedure compiles information that characterizes salient aspects of each spring's aquatic and riparian environment and the communities that they support. This inventory focused on locating spring sources and recording information to assess their biotic potential, prioritize the importance of individual sites for long-term monitoring, and guide management (see below). The Level II procedure was applied to springs with sufficient flow to support riparian communities. It includes more quantitative estimates of spring habitat and vegetation characteristics (see below).

The Level I inventory consisted of identifying and recording spring orifices (source or water

emergence points) using a Trimble Geo XH GPS unit; making site maps and descriptions; evaluating current and historic natural and anthropogenic disturbance; collecting benthic macroinvertebrates; and measuring water quality (water temperature, dissolved oxygen, pH, total dissolved solids [TDS], and conductance collected with a YSI ProPlus meter, and alkalinity, chloride, magnesium, sulfate, and calcium concentration with a YSI field spectrophotometer). Water quality meters were calibrated each morning prior to the sampling event, and post-calibration was conducted at the end of each day to ensure the meter remained calibrated throughout the day. The crew also measured morphological characteristics such as brook length (if present) or wetted area of pool formations, water depth, discharge, substrate, emergent cover (vegetation), bank cover (vegetation), documented spring type, and took photo points. In addition, the crew documented presence of wildlife and common, rare, or exotic plants.

At the request of Buenos Aires NWR staff, additional habitat and vegetation data were collected in the area referred to as the Willow Pond. These data may serve as pre-treatment data for actions related to cattail removal from this area. Previously known orifices were also located and documented. Data collected from each spring were compiled in a Microsoft Access® database developed by U.S. National Park Service database managers. Data used to prepare this report were analyzed by querying this database (located in enclosed CD).

Results and Discussion

Arivaca Cienega currently exists as a series of pools connected by channels of Arivaca Creek (Figure 1) that appear to have been dug or dredged, and maintained by burms. Although several orifices were located (Appendix B), much of the water appears to seep into the cienega diffusely. The area is easily accessed by a trail that loops through the cienega. Water level in the willow pond located in the southwest corner of the cienega is controlled by a spring box. The majority of the disturbance in the area appears to be related to human activity. Although human activity appears to have been substantial and has significantly altered the natural condition of the cienega, the cienega appears to have recovered from the disturbance, as evidenced by the vigor of the native riparian vegetation. No sign of natural disturbance was detected.

Because of the large size of Arivaca Cienega, it was surveyed in four sections (Figure 2). Section 1 consisted of four pools separated by burms located in a braided stream channel in the northeast portion of the cienega. The upstream-most portion of this area was not accessed because it is located on private property. These pools ranged in length from 2 m to 100 m long, were less

than 1 m wide, and water was, on average, 20 cm deep. Substrate in the pools consisted of fines, particularly silt and sand. All data tables are presented in Appendix B.

Section 2 starts west of section 1 and includes the north-central and northwest sections of the cienega inside the boardwalk loop, consisting of three 2-4 m deep channels and several wet, marshy depressions. The channels ranged in length from 70 m to 280 m. Water flow into these channels is diffuse, and no orifices were detected. Water width in the channels was roughly 1.75 m and depth averaged about 30 cm. Substrate consisted of fines, particularly silt and sand.

Section 3 consisted of Willow Pond Restoration Site in the southwest corner of the cienega, a dry depression bordered by wetland vegetation. The survey began at the spring box near the boardwalk and focused on the channel from the spring box to Willow Pond.

Section 4 consisted of the remainder of the cienega, a pool connected to the main channel by a 10-m long spring brook. The channel is >1 km in length. Water width is about 2 m and depth is about 60 cm, though

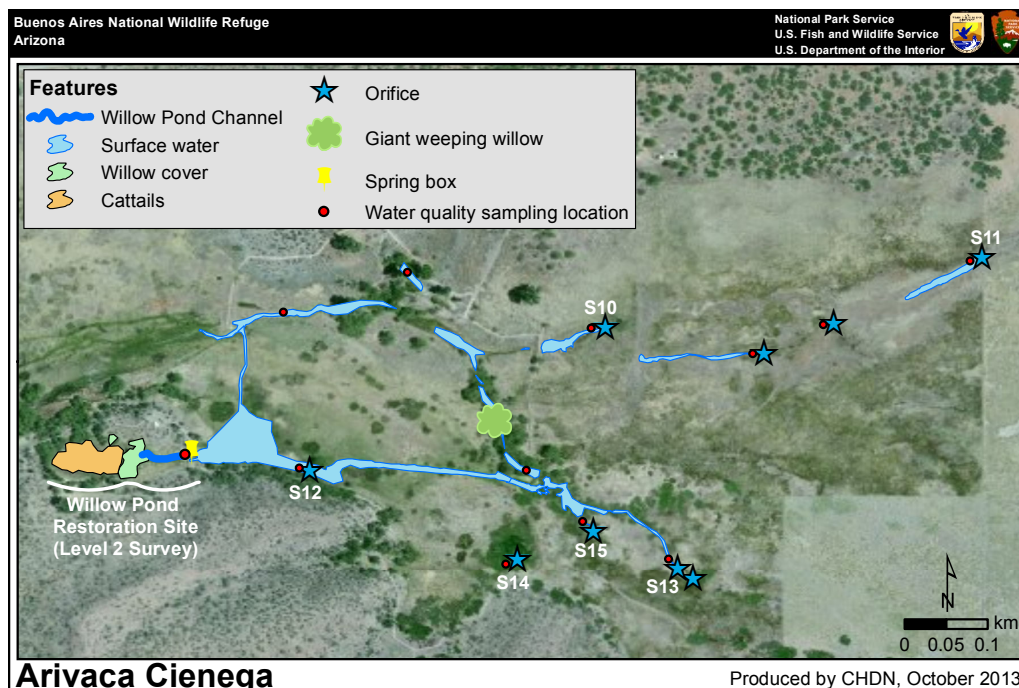
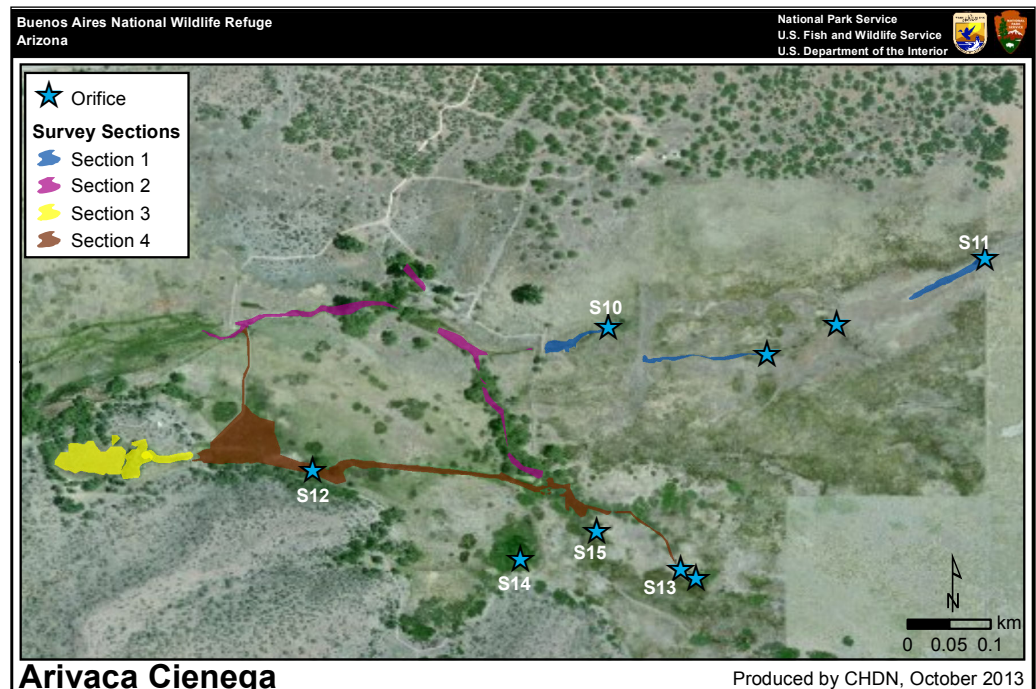


Figure 1. Map of Arivaca Cienega.

Figure 2. Map of Arivaca Cienega with pools identified.



these are highly variable within the channel. Substrate consisted of fines, particularly silt and sand. Estimated discharge is 50 L/min. Flow in the cienega is predominantly from east to west, originating in the southeast portion of the cienega from orifices S13 and S15 and moving toward the pool just west of S12 (Figure 2). This pool is largely a wide, shallow area of laminar flows. Water is pumped to the Willow Pond Restoration Site via a spring box on the western side of the pool. Water from this pool also appears to flow north along the channel next to the boardwalk, feeding additional areas in the northwest portion of the cienega. Maps and descriptions of the cienega are located in with the data sheets on the enclosed CD.

Vegetation

Typical wetland plants are found in the cienega, including cottonwoods (*Populus fremontii*), willows (*Salix* sp.), rushes (*Scirpus* sp.), cattails (*Typha* sp.), and a variety of grasses and forbs. A list of the species detected is included in Appendix C. Note this list reflects dominant or common species and is not intended to be a thorough inventory of plant taxa. A number of exotic plants were detected in the area, including

Bermudagrass (*Cynodon dactylon*), Johnson grass (*Sorghum halepense*), Russian thistle (*Salsola iberica*), and ragweed (*Ambrosia artemisiifolia*). Cover from emergent vegetation was variable, ranging from 10-75%. Vegetative cover on banks was fairly high, ranging from 70-100%.

The Willow Pond area consists of a 50-m spring brook with flow controlled by a spring box (Figure 3), leading into a pond that was dry at the time of sampling. The center of the pond was filled with cattails and dotted smartweed (*Polygonum punctatum*). Willows (*Salix goodingii*) are located along the perimeter of the pond. More intensive vegetation and habitat studies were conducted on the spring brook. Riparian vegetation along the spring brook (defined as consisting primarily of facultative or obligate wetland plants) extended more than 20 m beyond the wetted edge of the brook. Moving out from the bank perpendicularly, dominant species in the first 5 m consisted of cuman ragweed (*A. psilostachya*), Johnson grass (a non-native), and a golden eye (*Vigiera* sp.). Beyond 5 m, cuman ragweed was still common, with large buttercup (*Ranunculus macranthus*) and Apache beggarticks (*Bidens feruifolia*).



Figure 3. Willow Pond and spring box.

As part of the more detailed survey conducted at Willow Pond, point intercepts were measured along the thalweg of the spring brook from the spring box toward Willow Pond at 1-m increments for 30 m to identify different canopy layers. At each point, either large buttercup or cutleaf waterparsnip (*Berula erectua*) was in the first (shortest) canopy layer, except for meters 24-25, which had cattails. A second canopy layer consisted of either large buttercup or cutleaf waterparsnip, except for presence of *Eleocharis* sp. from meter 10-12. Other species encountered at low densities include floating marsh pennywort (*Hydrocotyle ranunculoides*) and dotted smartweed.

Habitat

Habitat within the spring brook is fairly uniform. Average wetted width of the channel is 1.7 m (range 0.70-2.6 m) and average water depth is 5 cm (range 1-17 cm). Wetted width of the channel generally decreased with distance from the spring box. There are no overhanging banks. The channel is covered consistently with fine substrates and detritus. Detritus is about 5 cm deep on average (range 0-30 cm) and is deeper closer to the spring box (up to 30

cm deep). Beyond 6 m downstream, detritus is rarely more than 5 cm deep. Emergent plants are found all along the spring brook. Cover ranges from 0 to 100%, however, more than half of the measurements had cover greater than 90%. Only three of fifteen measurements had cover less than 30%.

Water Quality

Water quality measurements were taken at 13 locations within the cienega. Water temperatures were fairly warm, ranging from 16.3 to 25.9°C. Temperatures were coolest in the southeast portion of the cienega, and warmest in the northeast portion of the cienega. Dissolved oxygen (DO) concentration ranges were 2.22-5.12 mg/L, which ranges from well below to just above the level necessary to protect fish and other aquatic life, according to the U.S. Environmental Protection Agency (EPA) standard for DO, which is 4 mg/L. DO levels are well below the 6.0 mg/L DO standard for the Arizona Department of Environmental Quality (AZDEQ) for warm waters. DO data are only available for the northeast portion of the cienega, as the meter failed to pass post-calibration on the days the other parts of the cienega were sampled. pH levels

varied from 6.93 to 8.52, well within AZDEQ standards. pH was lowest near S13 and S15 in the southeast portion of the cienega and highest in the northeast area of the cienega. Total dissolved solids (TDS) ranged from 183.3 to 721.5 mg/L. The EPA doesn't have a standard for TDS, and AZDEQ has set one only for the Colorado River, however, these TDS values in Arivaca Cienega are fairly low and would likely meet any standard. Electrical conductance ranged from 285 to 1,176 $\mu\text{S}/\text{cm}$; the pattern was similar, lower levels were measured near the orifices in the southeast portion of the cienega and highest in the northeast portion. TDS, conductivity, and pH were notably higher in the small (2 m-long) pool just west of the pool containing the S11 orifice.

Samples were collected for analysis of water quality using a field spectrophotometer. Alkalinity (the water's capacity to neutralize acids) was measured as concentration (in mg/L) of calcium carbonate (CaCO_3), bicarbonate (HCO_3^-), and carbonate (CO_3^{2-}). Alkalinity in water results from any dissolved species (though usually weak acid ions such as carbonic acid) that can accept and neutralize protons. Because carbon dioxide (CO_2) is soluble and relatively abundant in water, and carbonates are common minerals over much of the Earth, the property of alkalinity of freshwater is determined by the

presence of bicarbonates and carbonates. The $\text{CO}_2\text{—HCO}_3^-\text{—CO}_3^{2-}$ equilibrium system is the major buffering system in fresh water. Calcium carbonate levels ranged from 125 to 420 mg/L, bicarbonate levels ranged from 155 to 520 mg/L, and carbonate values ranged from 75 to 250 mg/L. These levels are typical for fresh water, given the range of pH values around neutral.

In addition to measuring alkalinity, concentration of common ions was also measured, including calcium (Ca^{2+}), chloride (Cl^-), magnesium (Mg^{2+}), and sulfate (SO_4^{2-}), all of which, when combined with bicarbonate and carbonate, constitute total salinity. Salinity of surface water depends on ionic influences of the surrounding land (geology), atmospheric deposition (e.g. wind-blown dust), and evaporation rates relative to precipitation (Wetzel 2001). Calcium is a required nutrient for growth of freshwater flora and fauna and has direct influence on population growth. Many diatoms and invertebrates have calcium as a component of their outer covering or exoskeleton. Chloride is influential in osmotic balance and ion exchange. Magnesium is a component of chlorophyll and is therefore required universally by plants. Sulfur is utilized by all living organisms for protein synthesis, however, our interests are related to pollution from fertilizer and atmospheric deposition.

Calcium levels range from non-detectable (less than 5 mg/L) to 155 mg/L. Calcium concentration ≥ 20 mg Ca/L is associated with hard water (Wetzel 2001). Chloride levels ranged from 0.3 to 11.3 mg/L. Concentrations between 1 and 100 mg Cl/L are common in freshwater. Magnesium levels ranged from 40-80 mg/L. Sulfate concentration ranged from 0-5 mg/L. Typical ranges for sulfate concentration in freshwater is about 5-30 mg/L.



Northwest area showing the channel of Arivaca Creek.

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Appendix A List of Attributes

The following elements were recorded during Level 1 surveys:

- Site Code—identification number for each spring within a national park or refuge. Consists of park or refuge name abbreviation and number
- Date the survey is conducted
- Person (Surveyor) conducting the spring survey
- Park Code—park or refuge name abbreviation
- 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=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.
- Description of site access
- Extent of sampling effort with comments
- Sample start and end times
- Total time spent sampling
- Global Positioning System (GPS) location and the datum of the spring source and terminus. 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.
- Photos. Photographs 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, photographer, subject, 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 site map where photos were taken.
- Site Description—description of overall ecological community and geologic setting in which the spring is situated.
- Site Map—includes locations of orifices, water quality measurements, photo points, and more.
- Important animals and plants. 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, (2) species that are indicative of spring characteristics (e.g., species of woody vegetation, obligatory and facultative wetland vegetation, crenobiontics), (3) species of management interest or concern, and (4) non-native species. Species should be identified, if possible. 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.

- Aquatic macroinvertebrates can be readily captured 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).
- **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. 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. Each spring is categorized as undisturbed, slightly, moderately, or highly disturbed:
 - **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.
 - **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.

- Dissolved Oxygen Concentration, (D.O., in mg/liter) using a field meter measured as close to the spring source as possible and in flowing water if available.
- Water Temperature in degrees Centigrade
- 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 and recorded in microsiemens.
- pH. pH is the measure of hydrogen activity, which indicates the acid/basic qualities of water.
- Total dissolved solids (TDS) in mg/L. Measure of all organic and inorganic substances dissolved in the water.
- The following are measured field spectrophotometer using water samples collected in the field:
 - Alkalinity—the water’s capacity to neutralize acids—measured as concentration (in mg/L) of calcium carbonate (CaCO_3), bicarbonate (HCO_3^-), and carbonate (CO_3^{2-}).
 - Chloride concentration in mg/L
 - Magnesium concentration in mg/L
 - Sulfate concentration in mg/L
 - Calcium concentration in mg/L
- 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.
- Estimated 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.
- 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.
- 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.)

- **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 (1-5 mm), gravel (>5-80 mm), cobble (>80-300 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.
- **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.
- **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.

Appendix B Data Collected in Arivaca Cienega

Orifice locations in Arivaca Cienega. Coordinates projected in WGS 84.

Orifice	Latitude	Longitude
S10	31° 34' 20.681" N	111° 19' 18.713" W
S11	31° 34' 23.391" N	111° 19' 4.051" W
S12	31° 34' 15.120" N	111° 19' 30.211" W
S13	31° 34' 11.284" N	111° 19' 15.900" W
S15	31° 34' 12.751" N	111° 19' 19.172" W

Feature locations in Arivaca Cienega. Coordinates projected in WGS 84. Refer to following figure for notes.

Features located with GPS coordinates.

Name	Latitude	Longitude	Feature	Notes
AC I	31° 34' 20.681" N	111° 19' 18.713" W	Secondary Orifice	4th pool (S10)
AC I	31° 34' 19.655" N	111° 19' 12.517" W	Secondary Orifice	3rd pool
AC I	31° 34' 20.823" N	111° 19' 9.825" W	Secondary Orifice	2nd pool
AC I	31° 34' 23.391" N	111° 19' 4.051" W	Primary Orifice	1st pool (S11)
AC I	31° 34' 19.423" N	111° 19' 18.399" W	Other	fence post
AC I	31° 34' 19.306" N	111° 19' 19.171" W	Other	plastic pipe
AC I	31° 34' 17.010" N	111° 19' 23.018" W	Other	weeping willow
AC III	31° 34' 15.760" N	111° 19' 34.789" W	Primary Orifice	spring box
AC III	31° 34' 15.733" N	111° 19' 34.787" W	Other	pipe
AC III	31° 34' 15.663" N	111° 19' 35.032" W	Other	pipe terminus
AC IV	31° 34' 10.908" N	111° 19' 15.288" W	Pool	1st pool
AC IV	31° 34' 11.284" N	111° 19' 15.900" W	Primary Orifice	2nd pool (S13)
AC IV	31° 34' 12.751" N	111° 19' 19.172" W	Secondary Orifice	side orifice off main channel (S15)
AC IV	31° 34' 11.667" N	111° 19' 22.123" W	Primary Orifice	no flow
AC IV	31° 34' 15.120" N	111° 19' 30.211" W	Secondary Orifice	S12

Condition. Scale of magnitude of disturbance on scale of 1-4 for roads, hiking trails, recreation use (rec), flow modifications, livestock, contemporary human use, historic human use, flood, wind, grazing (wild animals), insects, fire, or drought, and the type(s) of flow modification (if present). 1=no disturbance, 2=slight disturbance, 3=moderate disturbance, 4=severe disturbance.

Title	Roads	Hiking	Rec	FlowMod	Livestock	Contemp	Historic	Flood	Wind	Graze	Insect	Fire	Drought	Mod_Type
AC I	1	2	1	4	1	1	4	1	1	1	1	1	1	Dam Diversion;Excavation
AC II	1	3	3	4	1	3	4	1	1	1	1	1	1	Dam Diversion;Excavation
AC III	1	2	1	4	1	3	3	1	1	1	1	1	3	Pipe Diversion;Dam Diversion;Open Trough/Tank;Excavation
AC IV	1	2	2	4	1	4	4	1	1	1	1	1	1	Dam Diversion;Excavation

Spring Type and Setting. Includes date sampled, spring type, brook length in meters, estimated discharge in L/min, water depth in cm, water width in cm, cover of emergent vegetation (%), vegetative bank cover (%), and percentage of substrate in fines, sand, gravel, cobble, boulder, and bedrock substrate. Dashes indicate no data.

Title	Date	SpringType	Length	Discharge	Depth	Width	EmergCov	BankCov	Fines	Sand	Gravel	Cobble	Boulder	Bedrock
AC I	10/1/2011	Heleocrene	--	--	20	662	10	70	100	0	0	0	0	0
AC II	10/2/2011	Heleocrene	200	--	30	175	30	100	100	0	0	0	0	0
AC III	10/2/2011	Rheocrene	50	--	5	168	0	0	100	0	0	0	0	0
AC IV	10/3/2011	Heleocrene	1000	50	60	200	75	100	100	0	0	0	0	0

Water Quality. Includes date sampled, orifice where sample was taken, water temperature (Temp) in degrees Centigrade, dissolved oxygen (DO) in mg/L, pH, total dissolved solids (TDS) in mg/L, electrical conductance (EC) in $\mu\text{S}/\text{cm}$, shade conditions under which samples were collected, whether the spring was dry, and other notes about the sample. Dashes indicate no data.

Title	Date	Orifice	Temp	DO	pH	TDS	EC	Shade	Dry	Notes	QAQC Notes
Arivaca Cienega I	10/1/2011	Pool 1	25.7	3.15	7.33	183.3	285.7	Sun	NO		
Arivaca Cienega I	10/1/2011	Pool 2	28.2		8.52	721.5	1176	Sun	NO	Stagnant puddle	DO may be wrong
Arivaca Cienega I	10/1/2011	Pool 3	29.1	5.12	7.71	251.55	417.2	Sun	NO	Pond possibly excavated	
Arivaca Cienega I	10/1/2011	Pool 4	25.9	2.22	7.34	215.15	337.2	Sun	NO	Pond possibly excavated	
Arivaca Cienega II	10/2/2011	1	16.3	--	7.03	241.8	--	Shade	NO	Wooded channel	DO failed post cal
Arivaca Cienega II	10/2/2011	2	17.5	--	7.61	585	--	Partial	NO	Orifice 1 measurement taken just below roots of large, downed willow	DO failed post cal
Arivaca Cienega II	10/2/2011	3	16.7	--	7.6	261.3	--	Partial	NO	Channel/canal	DO failed post cal
Arivaca Cienega III	10/2/2011	Single	18.4	--	7.09	302.25	--	Shade	NO	YSI not saving data, error message	DO failed post cal
Arivaca Cienega IV	10/3/2011	1	17.9	--	6.92	221	339.9	Shade	NO	Primary	DO failed post cal
Arivaca Cienega IV	10/3/2011	2	18.3	--	6.93	214.5	329.8	Shade	NO	Secondary, flowing water	DO failed post cal
Arivaca Cienega IV	10/3/2011	Cienega	17.5	--	7.07	320.45	493.2	Shade	NO	Wallow, small muddy pool below trees	DO failed post cal
Arivaca Cienega IV	10/3/2011	3	17.4	--	7.07	218.4	335.9	Shade	NO	Clear pool beneath willow trees	DO failed post cal

Water Quality, Spectrophotometry. Included are orifice where sample was taken, concentration calcium carbonate (CaCO_3), bicarbonate (HCO_3), carbonate (CO_3), chloride (Cl), magnesium (Mg), sulfate (SO_4), and calcium (Ca), and notes about the samples. All units are mg/L. ND indicates the parameter was not detected.

Title	Orifice	CaCO_3	HCO_3	CO_3	Cl	Mg	SO_4	Ca	Location	Notes
AC I	Pool 4	125	155	75	0.8	75	3	26	Sample taken from Cienega I, Pool 4. West of the footpath and the benches	muddy, stagnant pond
AC II	1	420	520	250	0.2	80	4	155	Sample taken at Pool A	Second sample taken at Pool C.
AC II	2	180	220	105	6	40	0	ND	Channel	WC#2
AC III	Spring	150	185	90	8	40	0	40	Willow Pond. Sample taken under bridge at orifice (left bank). Below Spring Box	
AC IV	1	155	185	90	6.6	50	0	42	S13 Primary	Two other readings recorded on data sheet.
AC IV	2	160	200	95	8.5	55	0	36		Secondary, flowing water.
AC IV	Cienega	225	275	135	7	70	5	52		Cienega. Wallow, small muddy pool below trees.
AC IV	3	155	190	95	5.5	50	0	34		Tertiary. Clear pool beneath willow trees.

Willow Pond Stream Brook Habitat Measurements. Includes meters from spring box (moving downstream), wetted width (cm), water depth (cm), substrate size (mm), depth of detritus (cm), height of emergent vegetation (cm), and percent cover of shade.

Meter	Width	Depth	Substrate	Detritus	Veg	Cover
3.3	235	4.33	0.01	29.33	86.33	100%
6.6	260	5.67	0.01	10.67	90.67	97%
9.9	200	3.33	0.01	3.33	115.33	100%
13.3	170	7	0.01	4	8	0%
16.6	180	4.67	0.01	5	63.67	29%
19.9	190	6.33	0.01	6	102.33	91%
23.3	175	4.67	0.01	2	40.33	62%
26.6	120	8.33	0.01	2	66.33	53%
29.9	190	8.33	0.01	5.67	33.67	25%
33.3	175	3.67	0.01	2.67	85.67	53%
36.3	190	7.33	0.01	2.33	26.33	21%
39.9	150	3.67	0.01	3	50.67	62%
43.3	100	4	0.01	2.33	55	97%
46.6	70	3.33	0.01	4.33	48.33	100%
49.9	120	2.17	0.01	0.67	58.33	99%

Willow Pond Vegetation Canopy. Point-line intercept measures including meter from spring box (moving downstream), substrate, species in first (lowest) canopy level (species 1), and species in higher canopy levels. OW=open water, LI=litter. Species codes consist of the first three letters of the genus and species (see Appendix C).

Meter	Substrate	Species1	Species2
0	OW	BERERE	
1	OW	RANMAC	BERERE
2	OW	RANMAC	
3	OW	RANMAC	BERERE
4	OW	RANMAC	BERERE
5	OW	RANMAC	
6	OW	BERERE	RANMAC
7	OW	BERERE	RANMAC
8	OW	BERERE	RANMAC
9	LI	RANMAC	BERERE
10	LI	RANMAC	<i>Eleocharis</i> sp.
11	OW	RANMAC	<i>Eleocharis</i> sp.
12	LI	RANMAC	<i>Eleocharis</i> sp.
13	OW	RANMAC	BERERE
14	OW	RANMAC	
15	OW	BERERE	HYDRAN
16	OW	RANMAC	BERERE
17	OW	RANMAC	
18	LI	RANMAC	
19	OW	BERERE	RANMAC
20	OW	BERERE	RANMAC
21	OW	BERERE	RANMAC
22	LI	BERERE	
23	OW	<i>Typha</i> sp.	
24	LI	<i>Typha</i> sp.	
25	OW	BERERE	
26	OW	RANMAC	<i>Typha</i> sp.
27	OW	BERERE	RANMAC
28	OW	RANMAC	BERERE
29	OW	RANMAC	POLPUN
30	OW	RANMAC	

Shrub-Herb Cover. Included is meter sampled (moving downstream from spring box), side of bank, location on the bank (near is 0.5 m from wetted edge, far is 1.5 m from wetted edge), species, and cover class. Species codes consist of the first three letters of the genus and species (see Appendix C). Cover classes: 1=<1%, 2=1-5%, 3a=5-15%, 3b=15-25%, 4=25-50%, 5=50-75%, 6=>75%.

Meter	Side	Location	Species	Cover
3	Left	Near	Unknown grass	6
3	Left	Near	ASTFAL	2
3	Left	Near	<i>Bidens</i> sp.	2
6	Left	Far	<i>Bidens</i> sp.	2
6	Left	Far	CYNDAC	3a
6	Left	Far	Euphorbiaceae	2
9	Right	Near	<i>Bidens</i> sp.	3a
9	Right	Near	<i>Eleocharis</i> sp.	6
9	Right	Near	BERERE	2
12	Right	Far	<i>Bidens</i> sp.	3b
12	Right	Far	<i>Eleocharis</i> sp.	2
12	Right	Far	AMBTRI	2
18	Left	Near	<i>Eleocharis</i> sp.	6
18	Left	Near	RENMAC	3b
18	Left	Near	POLPUN	2
18	Left	Near	BERERE	2
21	Left	Far	AMBPSI	6
21	Left	Far	AMBTRI	4
21	Left	Far	<i>Eleocharis</i> sp.	4
21	Left	Far	<i>Bidens</i> sp.	2
24	Right	Near	<i>Typha</i> sp.	2
24	Right	Near	<i>Bidens</i> sp.	4
24	Right	Near	<i>Eleocharis</i> sp.	4
27	Right	Far	<i>Bidens</i> sp.	5
27	Right	Far	<i>Eleocharis</i> sp.	3b
27	Right	Far	AMBPSI	2

Appendix C List of Plants Detected

Table C1. List of plants detected at Arivaca Cienega, Buenos Aires National Wildlife Refuge.

Scientific name	Common name	Nativity
<i>Amaranthus</i> sp.		
<i>Ambrosia artemisifolia</i>	annual ragweed	Non-native
<i>Ambrosia psilostachya</i>	Cuman ragweed	Native
<i>Ambrosia</i> sp.		
<i>Ambrosia trifida</i>	great ragweed	Native
<i>Asclepias subverticillata</i>	horsetail milkweed	
<i>Berula erecta</i>	cutleaf waterparsnip	Native
<i>Bidens ferufolia</i>	Apache beggarticks	Native
<i>Bidens</i> sp.		
<i>Bouteloua</i> sp.		
<i>Celtis laevigata</i> var. <i>reticulata</i>	netleaf hackberry	Native
<i>Cynodon dactylon</i>	Burmudagrass	Non-native
<i>Cyperus</i> sp.	Cyperus	
<i>Eleocharis</i> sp.		
<i>Eragrostis lehmanniana</i>	Lehmann's lovegrass	Non-native
<i>Helianthus annuus</i>	common sunflower	Native
<i>Helianthus</i> sp.		
<i>Hydrocotyle ranunculoides</i>	floating marsh pennywort	Native
<i>Ipomoea</i> sp.		
<i>Lemna</i> sp.	duck weed	
<i>Polygonum punctatum</i>	dotted smartweed	Native
<i>Polygonum</i> sp.		
<i>Populus fremontii</i>	Fremont cottonwood	Native
<i>Proboscidea parviflora</i>	double claw	
<i>Prosopis</i> sp.	mesquite	Native
<i>Ranunculus macranthus</i>	large buttercup	
<i>Ranunculus</i> sp.		
<i>Salix goodingii</i>	Gooding's willow	Native
<i>Salix</i> sp.	willow	
<i>Salsola iberica</i>	Russian thistle	Non-native
<i>Scirpus</i> sp.	bull rush	
<i>Sorghum halepense</i>	Johnson grass	Non-native
<i>Sporobolus wrightii</i>	big sacaton	Native
<i>Symphyotrichum falcatus</i>	white prairie aster	Native
<i>Typha</i> sp.	cattail	
<i>Viguiera</i> sp.	goldeneye	
<i>Xanthium strumarium</i>	cocklebur	Native

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