PAKOON SPRINGS REHABILITATION FINAL REPORT

(TASK #9, AWPF GRANT CONTRACT #06-137WPF AND INCLUDING TASK #4 AND TASK #8 FINAL MONITORING REPORTS)

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1 EXECUTIVE SUMMARY

Located in the Mojave Desert, Pakoon Springs is one of the largest springs on the Arizona Strip, the portion of Arizona lying between the Colorado River and the Arizona-Utah border. It is the largest springs complex in Grand Canyon-Parashant National Monument and was recommended by Grand Canyon Wildlands Council, Inc. (GCWC) to the Bureau of Land Management (BLM) as the most promising site for rehabilitation. In June 2002, the BLM acquired Pakoon Springs Ranch (240 acres) through a donation by the Richard King Mellon Foundation, with assistance from The Land and Water Conservation Fund. The BLM partnered with GCWC to develop and implement a rehabilitation plan for the site, including a 5-10 acre pilot rehabilitation project. The Arizona Water Protection Fund (Contract #06-137WPF) funded a major portion of this Pakoon Springs rehabilitation project from 2006-2010.

Springs in the Southwest have such a lengthy history of human use that rehabilitation planning must consider anthropogenic disturbance (particularly fire and springs source modifications) as part of the springs' natural ecological condition. Archeological investigations in the region demonstrate that Native Americans used springs and streams for hunting, food gathering, and agricultural irrigation during the entire Holocene epoch. Historically, Pakoon Springs was developed and modified to provide water for livestock, agricultural irrigation, and domestic use. The surficial geology and soils of the Pakoon Springs site were highly disrupted by human activities. Many non-native plants and animals were introduced, including saltcedar, pomegranate, palm, Bermuda grass, mosquitofish, bullfrogs, and an alligator.

No pre-development photographs or descriptions of Pakoon Springs have been found. To plan rehabilitation of the site, we reviewed the literature and studied the physical and biological characteristics of Waunita, Burro, Tassi, Buckhorn, and other nearby springs complexes, most of which have been developed. Hillside seep and spring complexes, such as several of these, are common geomorphic springs types in the Great Basin and Mojave Desert. We also interviewed the previous land owner and several BLM employees who were familiar with the site. Even with this information, the highly altered condition of Pakoon Springs created many uncertainties regarding the appropriate target conditions for rehabilitation.

To inform rehabilitation decisions, we developed a digital orthophoto rectified contour map of the 56-acre rehabilitation area of the Pakoon Springs site, including the springs, channels, riparian and upland areas, from aerial photographs and ground control. Fifty-six soil profiles up to 5 ft (1.524 m) in depth were core sampled at the middle of each acre of the project area. Our team hydrologist compiled hydrologic features, piping, and other natural and anthropogenic water-related features of the site into a hydrologic map, including historic channel and pool locations. Land cover polygons, including discrete vegetation patches, stream channels, and roads and other anthropogenic features, were identified on 2006 true color aerial photography for the entire site, and were mapped on field sheets at approximately 1:100 scale. Three representative spring source water samples were collected for cation, anion and nutrient laboratory analysis and one stable isotope was collected and analyzed. Data previously collected by the USGS, BLM, GCWC and other sources were incorporated into the springs source location and mapping.

Hydrologic field monitoring for Pakoon Springs began in August 2006 with hydrologic elevation control establishment at ten water features that had current or historical hydrologic significance. Discharge, field water-quality, and air temperature at the spring outflow points were monitored quarterly to semi-annually based on locality availability and project timing. The spring source elevation (often at the bottom of existing ponds) provided the starting elevation for any spring mounds/hillside seeps or outflow channels recreated. The flow direction and character of the flow was used to guide rehabilitation and revegetation activities. In addition, vegetation monitoring was conducted quarterly.

Five priority areas or “arenas” were selected for the pilot rehabilitation project, and three springs habitat types were targeted among those arenas: limnocrene (open water), flowing water, and low gradient wet cienega meadows. All rehabilitation actions included consideration of how to achieve a landscape that required the minimum amount of maintenance and had the greatest long-term resilience. Berms had been constructed by previous owners to focus flow and facilitate diversion, irrigation, and agricultural uses of spring water. The berms were eliminated or reduced and the landscape reshaped around the spring sources. Recontouring the topographic profile supported flow connectivity, geomorphically appropriate habitats, and a natural appearance to the springs system. Non-native species of plants and animals were eliminated from Pakoon Springs where possible, however most of these require ongoing maintenance, as plant species such as tamarisk, palm and pomegranate have resprouted in limited numbers. Habitats were reconfigured to limit further non-native population invasion and expansion.

In Arenas 1, 2, 3, and 4E, existing bermed ponds were filled and recontoured into the configuration of regional hillslope springs. After filling with locally derived soil, springflow reemerged and rewetted areas around the spring source, expanding and migrating laterally over time, with seasonal variation. Recontouring eliminated large populations of bullfrogs in these ponds, and buried large stands of cattails. In Arena 4, where there was a large pond with a relatively high berm, we lowered the berm, excavated a deeper pool along the west side, and created a neoprene and rock lined outflow channel, reconnecting springflow (72 gpm to 86 gpm) to the previously almost completely dewatered Pakoon Wash (only a small seep or irrigation piping leak of 2gpm emerged in the channel). Recontouring uncovered a new spring source with significant flow at the northwest end of the pond. By autumn 2010, the perennial streamflow in Pakoon Wash extended approximately 1 mile downstream from the confluence with the Arena 4 outflow. A muskrat was observed swimming in the Arena 4 pond on two occasions, after construction was completed. The Kaibab Band of the Southern Paiute Tribe and numerous volunteers assisted with translocating cottonwood and willow to the new shoreline around the Arena 4 pond.

Revegetation was undertaken by translocating local native plant stock, with the goal of rehabilitating the site as a desert oasis within several years. Such habitat will be of particular value to migrating and summer resident birds. Feedback of vegetation into pedogenesis at the rehabilitation site is likely to require decades to centuries, but the geomorphic rehabilitation of the site has set the stage for that future soil redevelopment. Vegetation monitoring of the arenas at Pakoon Springs in September 2010 revealed low mortality, vigorous growth, and much natural recolonization on all arenas, including Arena 5 (a dryland habitat with lower recolonization potential). In 2010 a native chenopod (*Atriplex elegans*) extensively colonized peripheral, disturbed dryland habitat around Arenas 1-4, and quailbush also colonized that peripheral zone. Growth and cover expansion of planted native Goodding's willow, *Baccharis salicifolia, Anemopsis californica,* and bulrush are vigorous, and most plantings in wetland arenas have been successful. However, arrowweed (*Pluchea sericea*) pole planting success in Arena 4 was minimal.

Rehabilitation of Pakoon Springs enlarged and enhanced one of the largest springs complexes on the Arizona Strip, and recreated the longest perennial stream in Grand Canyon - Parashant National Monument. The results of progress in implementation have been better than expected, with springs re-emerging as hoped after filling of excavated ponds, and with surprising natural recolonization by spikerush, yerba-mansa, datura, bulrush, Goodding's willow, seep willow, Fremont cottonwood, and other native plant species.

Challenges still remain for removal of non-native bullfrogs and mosquitofish from Arena 4 and the flowing section of Pakoon Wash, as well as removal of Russian thistle, malta star thistle, Bermuda grass, cheat grass, tamarisk, and other plant species from the site in general. Promising attempts to remove bullfrogs, facilitated by the Arizona Game and Fish Department and the U.S. Fish and Wildlife Service, were complicated by seasonal logistical difficulties; however, a systematic plan for bullfrog removal at Pakoon Springs was developed based on the lessons learned in these initial attempts. Future planting and nonnative species control activities will be necessary. The Relict Leopard Frog (RLF) Recovery Team visited the site repeatedly and has emphasized the value of Pakoon Springs as a potential site for RLF translocation, once bullfrog control is successful.

When the deeper spring sources have not been damaged or heavily modified, springs ecosystem geomorphology and habitat rehabilitation can be accomplished. Appropriate stewardship and multiple use sustainability are critical foci of the missions of the BLM, the National Forest Service, other federal lands, and many state, local, and private managers. With critical funding assistance from the Arizona Water Protection Fund, the BLM and GCWC have changed the Pakoon Springs ecosystem from a highly modified and degraded condition to one in which natural ecosystem processes prevail. This effort is regarded by the BLM as one of the premier examples of successful partnership to achieve agency goals. While monitoring and additional work remains to be accomplished at Pakoon Springs, this project clearly demonstrates that collaborative partnerships focused on clear, well-defined goals and rigorous implementation and monitoring can be used to improve ecosystem function, sustainability and stewardship, even for highly degraded springs. Part of the success of this project was attributed to improving understanding of site history and pre-treatment condition, and carefully planning and implementing management actions. The stewardship formula of:

Inventory → Assessment → Planning → Implementation → Monitoring with feedback

was pursued rigorously through this project, and its applicability was clearly demonstrated by the success of this project.

2 INTRODUCTION

2.1 Site background and history

Springs in the Southwest have such a lengthy history of human use that rehabilitation planning must consider anthropogenic disturbance (particularly fire and springs source modification) as part of the springs' natural condition. Archeological investigations in the region demonstrate that Native Americans have used springs and streams for hunting, food gathering, and agricultural irrigation during the entire Holocene epoch. Native Americans were present at major springs in our region at the time of first contact with European explorers and settlers (e.g., in the Muddy River Valley, Nevada). European settlement in the mid- to late-1800s initially resulted in the excavation of water sources to create permanent watering holes for travelers and included the construction of small impoundments for water storage. As livestock husbandry has increased, larger springs were further developed to irrigate crops for livestock feed. Evidence of prehistoric Native American presence, and much evidence of historical modification for agricultural purposes exists at Pakoon Springs. Located in the Mojave Desert, Pakoon Springs is one of the largest springs on the Arizona Strip (an area extending north from the Colorado River to the Arizona border; Fig. 2-1).

We were not able to locate any pre-development photographs or descriptions of Pakoon Springs. In order to plan rehabilitation of the site, we examined site characteristics of Waunita, Burro, Tassi, Buckhorn, and other nearby springs complexes, including their topography, geomorphology, and physical and biological characteristics (Grand Canyon Wildlands Council, Inc. 2002; L.E. Stevens unpublished data). Hillside seep and spring complexes are common springs geomorphic types in the Great Basin and Mojave Desert. The highly altered and modified condition of Pakoon Springs resulted in many uncertainties regarding the appropriate target conditions for rehabilitation. All of the original springs sources at Pakoon Springs were excavated, some to greater than 12 feet below the original ground surface.

Our examination of springs geomorphology, soils, vegetation, and previous maps and photographs of Pakoon Springs during our preliminary site visits indicated the site originally contained perhaps as many as 10 discrete springs source areas prior to agricultural modification (Fig. 2-2). These sources were likely helocrene (wet meadow) springs and, based on comparison with other springs in the Grand Wash drainage, they likely were overgrown with wetland and riparian vegetation prior to settlement of the site.

Development of the springs for irrigation may have started with small excavations that removed vegetation and exposed spring sources. Outflow from those sources subsequently would have been channelized, with flow directed towards areas where crops were grown or pastures were created for livestock. Frequent re-excavation and devegetation would have been required to keep these water sources and channels flowing.

Pakoon Springs discharge likely drained to the west at the north end, and into the dry wash to the east from the central and southern springs sources. Collectively, the springs appear to have a relatively low measurable discharge (<100 gpm), and many individual sites do not have sufficient flow or natural disturbance to prevent overgrowth by wetland and riparian vegetation. Similar springs in the region usually do not have large outflow channels, but may have small rivulets of water or small areas of shallow, standing water. Pakoon Springs, however, is the only springs complex in the region that can naturally support a limnocrene (pool-dominated) habitat, a geomorphic feature of considerable importance to waterfowl, bats, and other species requiring open water.

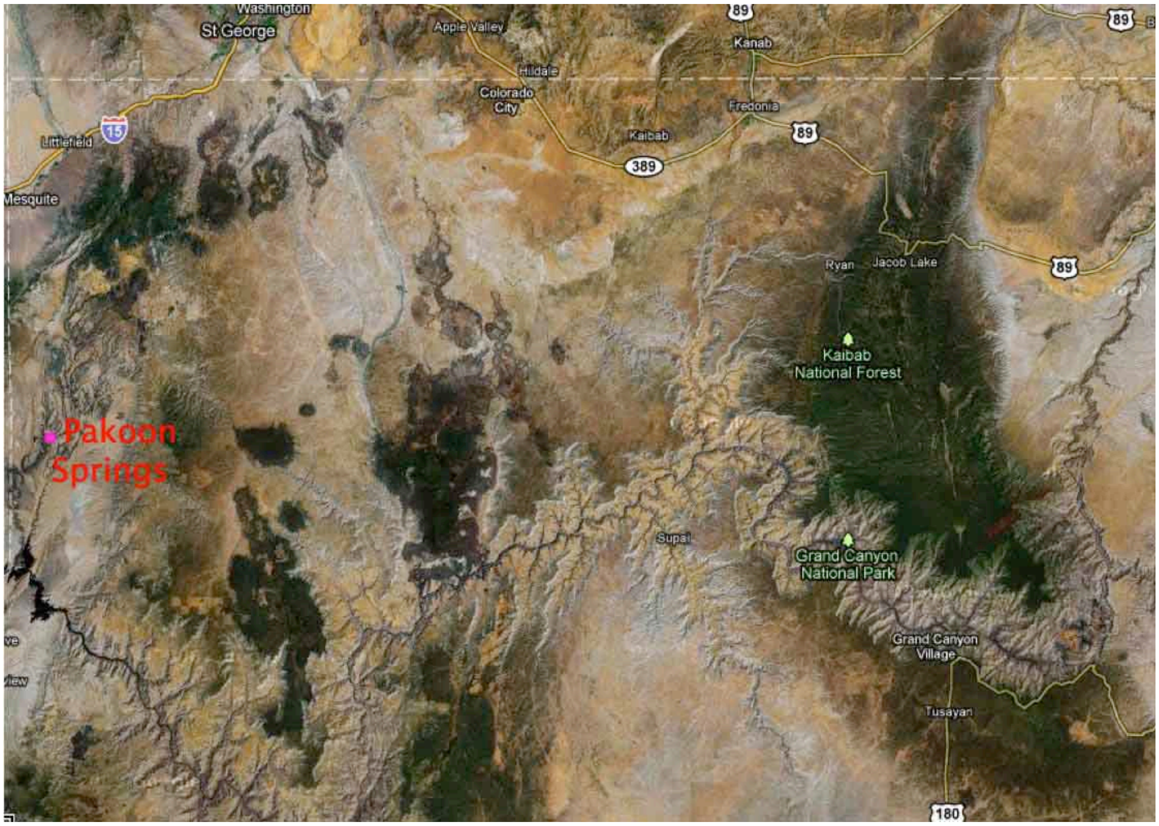


Figure 2-1 Location map showing Pakoon Springs near the Nevada-Arizona border, near Lake Mead. The region extending north and west of the Colorado River to the Arizona-Utah border is known as the Arizona Strip.

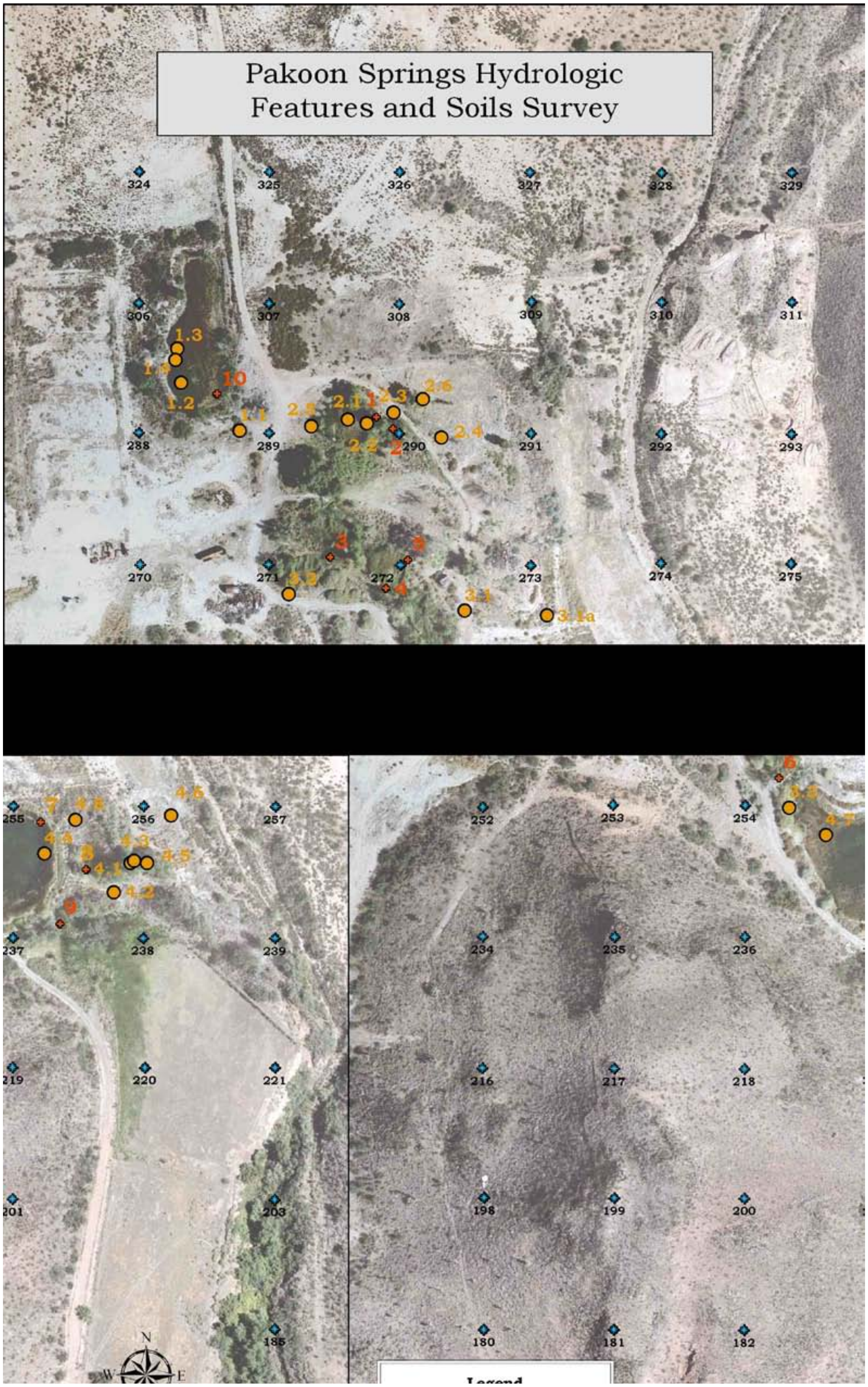
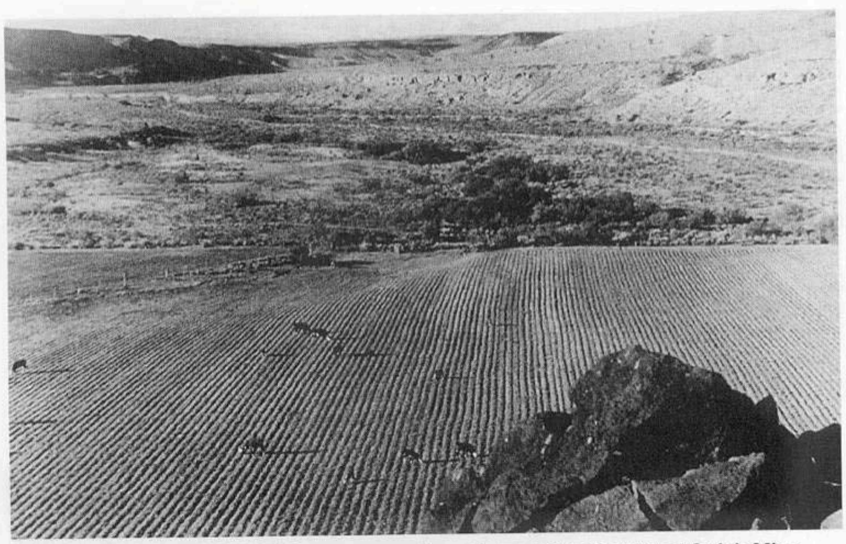


Figure 2-2 GIS map of Pakoon Springs showing water surface elevation locations for 10

likely spring sources, a grid of soil cores and field monitoring locations (for complete map data see Table 7-1 and Table 7-2)

Large areas of the Pakoon Springs Ranch property were leveled for irrigated alfalfa or other crop farming, and much water conveyance infrastructure was installed. Irrigation at Pakoon Springs likely began with the development of a water source for a small homestead at least by 1915, and probably prior to that time. Subsequent owners of the property gradually expanded the agricultural capability by increasing the amount of water storage and installing the elaborate, underground irrigation piping system. The southernmost Field 5 has long been used for agriculture, as demonstrated in the attached 1956 photograph (Fig. 2-3), with cattle foraging across that deeply furrowed field. The fields also contained a vast underground irrigation system.

100 BEYOND THE RANGES



Ranch at Pahcoon, 1956. This was an oasis on the road to the Grand Gulch Mine. Photo by W.R. Averett.

Figure 2-3 Photo of southern half of Pakoon Springs in 1956 (from Averett, W.R. 1997. Beyond the Ranges. Published by the Author, Grand Junction., Colorado).

Wet cienega desert springs complexes in this region typically produce a plant community that is tightly structured by the moisture gradient. Such springs habitats often contain: 1) an interior wetlands assemblage composed of sedges, rushes, and cattail, surrounded by 2) riparian shrubs (especially seepwillow, arrowweed, honey mesquite) and trees (particularly Goodding's willow and sometimes Fremont cottonwood), and 3) often are surrounded by dry riparian/paleosprings jimmyweed (goldenweed), saltgrass, inkweed, saltbush, and sometimes screwbean mesquite. We used these concepts and a generalized vegetation model to develop the Pakoon Springs Rehabilitation Plan, including enhancement or rehabilitation of wet cienega wetlands, limnocrene, and peripheral riparian habitats.

2.2 Oral history

An oral history of Pakoon Springs in included as Appendix 7.1. The oral history includes a BLM interpretive staff interview with prior landowner Charles Simmons and notes of interviews by R.J. Johnson and L.E. Stevens with Mr. Simmons and his caretaker of Pakoon Springs, Ralph Clarke.

2.3 Statement of the problem

Pakoon Springs is the largest springs complex in Grand Canyon-Parashant National Monument (GCPNM) and the most promising one for restoration. For at least the past century, Pakoon Springs was developed and modified to provide water for livestock, agricultural irrigation, and domestic use. Perennial flow to Pakoon Wash was diverted through an extensive irrigation pipe system and released onto agricultural fields resulting in little to no stream flow in the channel, and eliminating the floodplain. The extent of riparian habitat was greatly reduced, and ecosystem function was disrupted. Many non-native plants and animals were introduced, including salt cedar, pomegranate, palm, Bermuda grass, mosquito fish, bullfrogs, and an alligator.

2.4 Project goals, objectives and benefits

In June 2002, the Bureau of Land Management (BLM) acquired the Pakoon Springs Ranch (240 acres) through a donation by the Richard King Mellon Foundation, with assistance from The Land and Water Conservation Fund. The Bureau of Land Management partnered with Grand Canyon Wildlands Council, Inc. to develop a restoration and rehabilitation plan of 56 acres of spring, riparian, wetland and upland habitat, and to implement a pilot restoration project on 5-10 acres. The Arizona Water Protection Fund (Contract #06-137WPF) funded a major portion of this Pakoon Springs restoration project work during 2006-2010.

The goals of the Pakoon Springs project were to 1)restore and enhance the native biodiversity, ecological function, and the pre-development riparian habitat characteristics of Pakoon Springs, and 2) to provide an outdoor venue for natural and cultural resource education, spring rehabilitation interpretation, and recreation on the Grand Canyon – Parashant National Monument. The project objectives included: creating a land survey map with initial hydrologic, soils, and vegetation data; developing a rehabilitation plan; completing the approximately 10-acre pilot rehabilitation; monitoring the rehabilitation progress through rephotography and vegetation surveys; and informing the public and other partners through volunteer activities, presentations, and site visits.

Pakoon Springs rehabilitation/enhancement was designed to provide the following project benefits:

1. Expanded native riparian habitat
2. Proper hydrologic function, as well as proper pool, channel, and wetland geomorphology, and
3. Habitat for migrating waterfowl and wildlife and potentially for species of special concern.

2.5 Tasks to achieve project objectives

The Arizona Water Protection Fund grant contract #06-137WPF lists the tasks undertaken to achieve the project objectives. These tasks are summarized below.

<u>**Task 1:** Permits, clearances, authorizations, and agreements</u>

Obtain and submit to the Project Manager all necessary permits, authorizations, clearances and agreements, and perform any consultations required to complete the tasks. The requirements shall be met before any ground disturbing work is performed.

Task purpose: To comply with all local, state, and federal permit requirements and laws.

See list of submitted documents in section 3.1

<u>**Task 2:** Feasibility Study Plan</u>

Develop and submit a feasibility study plan, which details all components of the feasibility study and includes individual plans for: land surveys, hydrologic surveys and monitoring, soil surveys, and vegetation map and surveys.

Task purpose: To propose a framework, with evaluation criteria and data, upon which to write a comprehensive feasibility study.

The feasibility study plan presented the methods listed in section 4.

<u>**Task 3:** Land Survey Maps</u>

Generate land survey maps, which include an orthophoto rectified contour map of the 56-acre rehabilitation site and a GIS map with site topography and the location of significant features.

Task purpose: To produce detailed maps that identify the site's geomorphologic characteristics and landscape features.

The land survey maps are presented as Figs. 4-1 and 4-2 are attached as Appendix 7.3

<u>**Task 4:** Hydrologic and Soil Surveys and Hydrologic Monitoring</u>

Conduct hydrologic surveys and soil surveys. Hydrologic monitoring data will include field chemistry measurements, spring discharge, and inorganic lab analyses of sampled springs. The information gathered will be used to determine optimum channel and pool locations and revegetation during rehabilitation.

Task purpose: To characterize the groundwater, springs, and soil profiles of the project site.

See hydrology results and map in section 4.4 and soil surveys results in section 4.3

<u>**Task 5:** Vegetation Surveys and Map</u>

Conduct vegetation surveys and construct a vegetation map.

Task purpose: To provide detailed description of the vegetation at the 56-acre site prior to rehabilitation efforts and to identify any unique floral species that may be present.

See vegetation survey results and map in sections and 4.7.

Task 6: Feasibility Study and Rehabilitation Plan

Compile all information gathered from the aforementioned plans and maps to write a comprehensive feasibility study. The scope of the feasibility study will encompass the springs, wetland, riparian, and upland areas of the entire 56-acre site, and will identify priority areas for rehabilitation using raking criteria. The rehabilitation plan shall detail the implementation and subsequent monitoring of a pilot rehabilitation project as well as list potential future options for the design and rehabilitation of the entire project site.

Task purpose: The feasibility study will be used to rank priority sites for rehabilitation. The rehabilitation plan will detail the pilot rehabilitation project and describe strategies and costs of future phases of rehabilitation.

The rehabilitation plan is attached in Appendix 7.5

Task 7: Implementation of Pilot Rehabilitation Project

Implement the rehabilitation and revegetation of pilot site identified in the feasibility study and rehabilitation plan. Work includes rehabilitation of the site’s springs, channels, pools, wetlands, and upland; removal of non-native flora and fauna; and revegetation.

Task purpose: To restore and revegetate the springs, channels, pools, wetlands and upland of a 5 – 10 acre site as a pilot project.

See the descriptions of rehabilitation and specifics for each of the arenas in section 4.8.

Task 8: Vegetation monitoring

Monitor revegetation growth and survival as described in the rehabilitation plan.

Task purpose: To measure the success of revegetation efforts at the pilot rehabilitation site.

See final vegetation monitoring results in section 4.7.

Task 9: Final Report

Prepare and submit a comprehensive final report in accordance with AWPF final report guidelines. The final report shall include a summary of all methods used, outcomes of all tasks, analysis of all project data, suggestions for any changes or future actions, and an evaluation of the success of meeting project objectives. And provide all data generated under this contract.

Task purpose: To provide a comprehensive final report for public distribution that gives a detailed description of the project and showcases its benefits to the State of Arizona.

3 METHODS

The methods used to plan, survey, monitor, construct, revegetate, and remove non-native species are detailed in the corresponding sections below.

3.1 Permits, clearances, authorizations, and agreements

The following permits, clearances, authorizations and agreements were necessary to conduct the project and were obtained or completed and submitted to AWPF according to appropriate local, state and federal laws and requirements:
AWPF Contract #06-137WPF
Bureau of Land Management Assistance Agreement (with Grand Canyon Wildlands Council)
Land Title Deed
Proof of Water Rights
Hazmat Clearance
Cultural Clearance and SHPO Concurrence
COE Letter of Concurrence
Environmental Assessment (EA-AZ-130-2007-0048)
1998 Programmatic Biological Opinion with the FWS (#2-21-96-132).

3.2 Feasibility study plan

The feasibility study plan presented the detailed methods discussed below. These methods were identified as the most current appropriate techniques through literature search, agency discussion/review, and professional expertise.

3.3 Land survey and mapping

We developed a digital orthophoto rectified contour map of the 56-acre rehabilitation site, including the springs, channels, riparian and upland areas from aerial photographs and ground control. The aerial photos were produced from an aerial survey of Pakoon Springs flown by Kenney Aerial Mapping. These data were used to produce a GIS map including georeferenced site topography, soils, location of springs, ponds, and other surface water features and vegetation from the aerial photographs, along with an appropriate map scale and map legend clearly delineating all mapped features, lines, points and polygons. The GIS database provides map referenced photo points of all important site features, following AWPF recommendations describing reference site photography protocols (below).

Survey control points were established with ½” (#4) rebar, 18” long, or 60 penny (60d) nails. High-resolution aerial images were collected, and photo aerotriangulation models were created, with contours derived from those models. Aerial photogrammetry panels were made of white surveyor’s flagging material and were placed in the approximate positions specified by the photogrammetrist. These panels were located with a Topcon GTS-230W (Tokyo, Japan) total station survey instrument , using Tripod Data Systems (Corvallis, OR.) version 4.2 Survey Pro data collection software. Redundant measurements to each panel were taken to reduce instrument error, and recorded in the data collector. We determined the boundary of the disturbed area and set panels outside of it to include the entire disturbed area.

The data were reduced to Cartesian coordinates. We determined the boundary of the disturbed area and set panels outside of it to include the entire disturbed area. These and other positions were translated to match the handheld GPS coordinates generated in the field using a Garmin Vista CX (Olathe, KS) GPS unit, holding the position of the southwesterly-most panel, Panel Point 10 (PP10). The GPS derived direction between PP10 and PP2 was held as the fixed bearing.

The geographic coordinates were projected into North American Datum 1983 (NAD83) Arizona State Plane Coordinates, West Zone, International Feet. The GIS data file was generated with these values, and northings were reduced by 1,906,000, and eastings were reduced by 620,000. Elevations are based on an assumed elevation of 1000 at point 1 (nail on top of hill), thereby creating a local elevation network. PP2 was raised by 0.2’ to match check elevations for panels 1 and 5. No scaling was performed.

State Plane coordinates were based on the handheld GPS values for PP12, with the azimuth between PP10 and PP2 used for final orientation. No scale factor was applied. This level of accuracy was sufficient for establishing georeferencing at the site, for other applications (soils, vegetation, and cultural mapping), and for planning purposes; however, additional ground surveying was required to site specific elements of the rehabilitation plan. Land surveys were necessary to clarify flow direction on flatter portions of the site, and to relate soil core and groundwater depth information to rehabilitation planning.

3.4 Hydrologic survey monitoring overview

A hydrologic survey was conducted at the beginning of the project that included identification, mapping, and photo documentation of spring sources and related features. Discharge, field water-quality, and air temperature at the spring outflow points were monitored quarterly to semi-annually based on site availability and project timing. Three representative spring source water samples were collected for cation, anion and nutrient laboratory analysis and one stable isotope was collected and analyzed. Other data collected from the USGS, BLM, and other sources were incorporated into the springs source identification and mapping. A hydrologic map with historical channel and pool locations was produced based on the topographical interpretation from the digital orthophoto rectified contour.

3.5 Discharge measurement methods

Discharge was measured using the appropriate method for each spring outflow or seep, if discharge was sufficient and measurements were possible. The discharge measurement technique used was not known until the measurement location was selected. Channel configurations varied from location to location and sometimes within each location. The appropriate method was used at each location conforming best to channel shape, conditions, and discharge and which minimized site disturbance. The volumetric method was selected for all but one of the measurement points recorded for Pakoon Springs discharge. A portable parshall flume was the other discharge technique used; it was used to measure discharge from the largest discharge volume at Pakoon Springs (Arena 4). Measurement techniques were temporary and the sites sampled were returned to their original condition after measurements were made. The two different discharge methods are described below.

The volumetric measurements procedure (USGS - Buchanan and Somers, 1984: p. 61-63) was used for most Pakoon Springs discharge measurements. The procedure for measurement is as follows: A temporary earthen dam is constructed using earth or nonpermeable materials. Water is diverted through a temporary pipe and flow is allowed to stabilize prior to measurement. A volumetric container is used to catch discharge from the pipe and the time to fill the container is recorded. Flow is recorded three to five times over a time interval, as appropriate. The mean value is used as the measurement. The following variables were recorded at each volumetric measurement monitoring point: name of hydrologist, date and time of sampling, container volume, time to fill container, calculated discharge, and comments.

The portable Parshall Flume procedure (Flume) (USGS - Buchanan and Somers, 1984: p. 59-61) was used for discharge originating from the pond of Arena 4. The procedure for selecting and performing a flume measurement is as follows: The measurement site selected should be a low gradient channel with fine-grained bed material that will allow discharge to pool upstream of the flume. The flume is placed in the channel with wing walls of the flume pointed upstream in such a fashion as to focus as much flow as possible through the regular profile of the opening of the flume. Leakage under and around the flume is eliminated or minimize using impervious materials and soil. The flume requires free fall of water out the downstream end of the flume and the floor of the upstream section is leveled both longitudinally and transversely using a bubble level. Flow is allowed to stabilize prior to measurement. Gage height is recorded 3 - 5 times over a 10-15 minute interval. A standard rating curve for the flume is used to translate gage height to discharge. The mean value for discharge is calculated and recorded.

The following variables were recorded at each parshall flume discharge monitoring point: name of hydrologist, date and time of sampling, gage height, and comments.

3.6 Water quality field measurement methods

Electrical conductivity (EC), pH, and temperature field water-quality measurements were recorded three to five times from flowing water discharge areas with uniform flow, stable bottom conditions, and where constituents are mixed along the flow path, as possible, as cited in the USGS Field Manual chapter A1, 1.2.1.A, p. 2 & 6.0.2 A p.2: Field water-quality measurements from still water sites are taken using a vertical profile and spatially distributed to accommodate each site, as possible. A Hydac EC, pH, and temperature meter, or equivalent, is used for measurements (USGS Field Manual chapter A6, 6.1, 6.3, and 6.4). After selection of the measurement location, discharge water is allowed to contact the instrument sensor for one minute or until EC and temperature values have stabilized and then measurements are recorded. This procedure is repeated three to five times. The pH measurements for flowing water sites is determined by collecting a quantity of water in a container that allows complete submergence of the pH probe. Measurements are recorded when pH values stabilize. This procedure is repeated three to five times. The mean value is used as the measurement value.

The following variables were recorded at each water quality monitoring point: name of hydrologist, date and time of sampling, water-quality monitoring start and end times, field water-quality instrument used, calibration date, pH, electrical conductivity (EC) (цS/cm @ 25°C), water temperature, air temperature, and comments.

3.7 Laboratory-based water quality collection methods

Samples were collected at the location with the highest discharge and at arenas with varying discharges and field water-quality parameters.

Laboratory samples were collected in containers that were pre-cleaned with a 10% HCl acid solution three times, rinsed with deionized water, and then rinsed with spring discharge water prior to sampling. Filtering was completed using a 0.45 micron filter for those analytes that required filtering and preserved per standard protocol, as appropriate. Sample containers were labeled, sealed, and placed on ice under chain-of-custody for transport to the certified analytical laboratory.

3.8 Water quality assurance and quality control methods

Calibration of water-quality instruments follows USGS Field Manual chapter A6, 6.1.1 p.2, 6.3.2 pp. 1-4, 6.4.2 p. 1-5: When the Hydac or equivalent instrument is used for EC, pH, and temperature measurements, it was calibrated in the field before and after each day's measurements. Calibration solutions used for EC accommodate anticipated EC values for each site, i.e., 1,000 µmhos/cm. Calibration solutions used for pH include pH values of 4, 7, and 10. Calibrations are recorded in an instrument specific calibration log book. Duplicate water-quality measurements are randomly collected at spring monitoring points using a different field meter. The duplicate measurements are compared to the initial measurements to determine if additional instrument calibration is necessary. If a disparity is recognized at greater that 10% then both meters are recalibrated.

3.9 Soil quality and groundwater depth and distribution surveys

A grid of GPS points for soil cores was established from the base map (see Fig. 2-2), and used to position soil and depth-to-groundwater measurements. Subsurface soils were measured on 56 (1/ac) soil profiles up to five feet in depth, or until instrument refusal. Characteristics measured included: gravimetric soil moisture, soil texture and composition, soil salinity, and pH in a 1:1 mix of deionized water. These soil core samples were also analyzed to assist with indentifying substrate conditions prior to rehabilitation plant species selection.

Soil type was evaluated by determining color using a Munsell color chart. Soil pH was measured by creating a 1:1 mix of soil and distilled, deionized water that was allowed to equilibrate for 10 min, and measured with a calibrated Eutech PH Spear Model 466 (Oaktron ®) pH meter. Soil salinity (ppm) was measured using the same soil:water mix as above, using a calibrated Eutech ECTester Model No. 11 (Oaktron®) salinity meter.

When groundwater was encountered during these soil profile evaluations, the depth to groundwater was measured, as were field geochemistry characteristics of electrical conductivity (цS), pH, and water temperature.

3.10 Photodocumentation

Photographs were taken from fixed reference points, such as ledges or large rocks and in accord with AWPF protocols. Photo points were marked and photographed in relation to fixed objects,.

Photo metadata were recorded (camera type, film speed, etc. as appropriate). All fixed reference point monitoring photos were taken without zoom using a Konica Minolta DiMage Z2 (4.0 megapixel) digital camera. In addition, close up photos with various digital cameras for local comparison of changes were taken throughout the arenas and during construction activities. Digital photo images were easy to incorporate into the information management system and to composite into panoramic view.. We selected three main photo image recording sites, with an average of 10 photos per recording site to produce the panoramic views. These photos were repeated at each site visit (with a minimum of twice annually, coinciding with discharge measurements, field surveys, vegetation monitoring and/or construction efforts).

A new photodocumentation site was established in July 2009 to provide an improved view of the rehabilitation site from the east side (looking west).

3.11 Vegetation surveys and mapping

Vegetation Polygons

We created a topographically-based vegetation map of the 56 acre Pakoon Springs site using the digital ortho-rectified contour map (Grand Canyon Wildlands Council, Inc., 2007) and the aerial photographs collected during preparation of that map. Land cover polygons, including discrete vegetation patches, stream channels, and roads and other anthropogenic features, were identified on 2006 true color aerial photography for the entire site, and were mapped on field sheets at approximately 1:100 scale. Prior to the field visits in mid-March, 2007, relevant polygons were drawn on Mylar sheets, and those maps were used during field mapping to distinguish distinct cover types.

Polygons were ground-truthed during a field visit in mid-March 2007. This site visit timing was presumed to be appropriate, as winter annual plants would be visible and rare pediocacti were likely to be in bloom at that time. However, the 2006-2007 winter was a drought, with near-record low precipitation, and dry conditions prevailed for 1.5 years prior to our visit. Dry conditions likely were responsible for the low diversity of winter annuals and the lack of flowering and degraded condition of many plants we detected on the site. Nonetheless, we mapped the site during the March 2007 visit, and continued to search for additional species in subsequent visits. All plant species were recognized in the field or, due to extremely dry conditions over the prior year, were in such degraded condition that collection of identifiable material was not possible. Specimens of sufficient quality that were collected following wetter conditions were prepared for preservation as herbarium specimens and housed at the Museum of Northern Arizona, with vouchers provided to the BLM, if requested.

Percent cover of each plant species in each polygon in four strata was determined in the field: ground cover (GC) as 0-4 meter (m)-tall graminoid, wetland-deciduous, and/or herbaceous-deciduous cover; shrub cover (SC) as 0-4 m-tall perennial woody cover; middle canopy cover (MC) as 4-10 m-tall woody perennial cover; and tall canopy cover (TC) as >10 m-tall woody perennial cover.

Rare plants search

We took special care to search for rare and listed plant species on the site. We compiled a list of all federally listed plant species occurring in or near the Arizona Strip which could potentially be affected by the rehabilitation activities at the Pakoon Springs site. This list was compiled from the Merriam-Powell Colorado Plateau website (http://www. cpluhna.nau.edu/ Biota/plants.htm; last accessed 27 Feb 2008) and from the Arizona Rare Plant Committee (No date). We analyzed our field data and species lists to determine whether any of those species were likely to occur at Pakoon Springs.

3.12 Rehabilitation plan

Priority site ranking criteria

The focus of rehabilitation/rehabilitation activities at Pakoon Springs included five high priority areas (Fig. 3-1) where springs emerged pre-rehabilitation or in recent time, and where there was evidence of long-term springs existence, as demonstrated by long-lived wetland or riparian vegetation, such as yerba-mansa or large Goodding's willow trees. Criteria for definition of these arenas was based on the hydrologic features, soils and flow data, and on the presence of berms, which we assumed represented springs sources (possibly multiple), that had been excavated and bermed to create open-water ponds. Rehabilitation planning is described separately in Section 4.8 below for each of these five arenas. The outlying lands did not receive direct attention under this project, but rehabilitation of those sites is described here as well, for the purposes of documenting the long-range vision for this highly developed parcel of land.

Overview

Three springs habitat types were chosen for rehabilitation targets among the five priority areas or "arenas": limnocrene (open water), flowing water, and low-gradient wet cienega meadows. The selection and location of these habitat types were informed by the data collected during site visits, agency discussion, and previous rehabilitation experience (e.g. Ash Meadows, Nevada), All restoration actions planned included consideration of how to achieve a landscape that requires the minimum amount of maintenance and has the greatest long-term resilience.

Planning decisions included recontouring the topographic profile to support flow connectivity, geomorphically appropriate habitats, and a natural appearance to the springs system. The berms were eliminated or reduced and the landscape reshaped around the spring sources.
In the plan, the elevation of the spring sources (often in the bottom of existing ponds) controlled rehabilitation activities. The starting elevation for any spring mounds/hillside seeps or outflow channels was the spring source elevation. The flow direction and character of the flow was used to guide rehabilitation and revegetation activities. The preexisting contours on the base map were overlain with target contours for the recontouring (Fig. 3-1) and a number of target relative elevations were marked on surveyed stakes.

The revegetation planning decisions included translocating local stock, with the goal of restoring or rehabilitating a desert oasis within several years, of particular value to migrating and summer resident birds. Non-native species of plants and animals were also included in the rehabilitation planning, to be eliminated from Pakoon Springs where possible, and habitats reconfigured to limit further non-native population invasion and/or expansion.

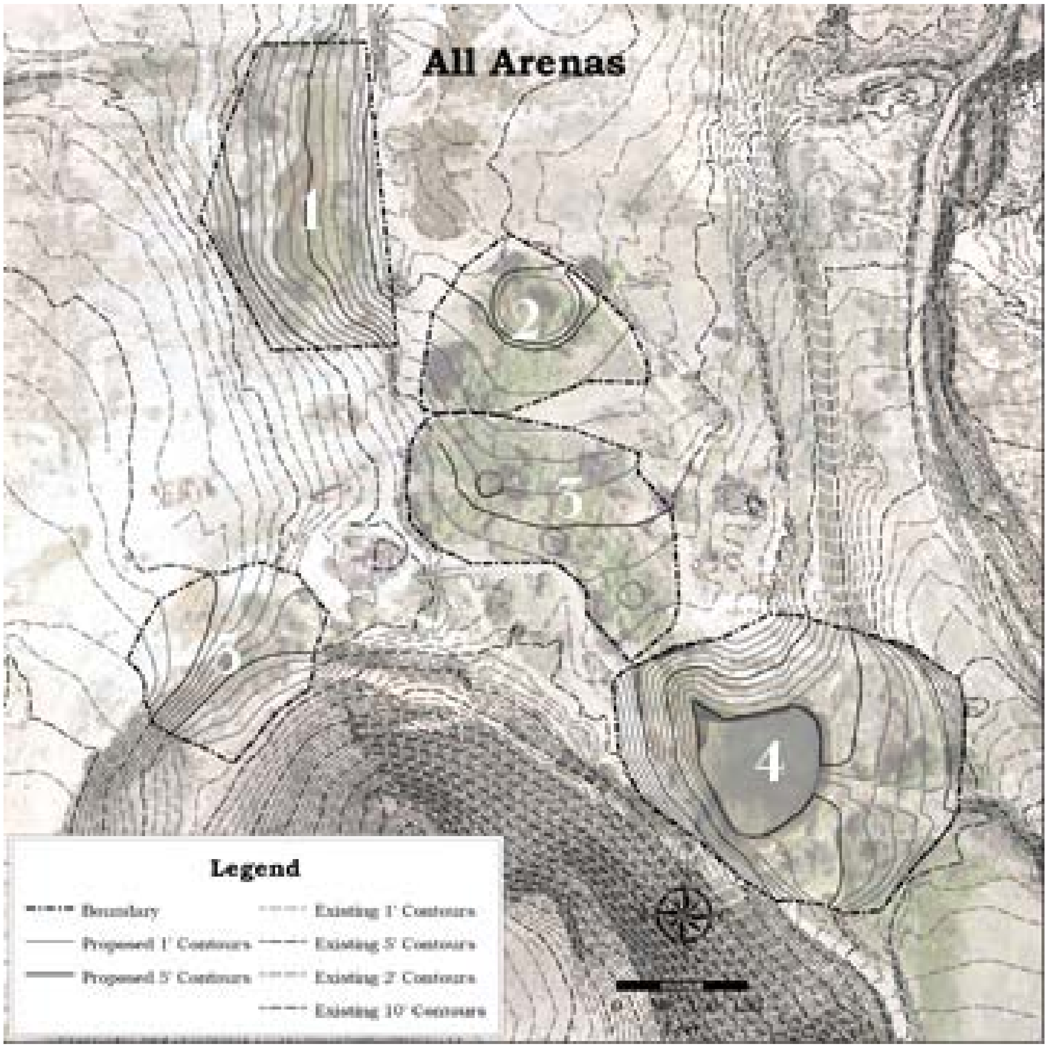


Figure 3-1 Map of the 5 rehabilitation arenas with existing and planned contours.

3.13 Rehabilitation implementation

Construction process

Implementation specific to each of the 5 arenas is discussed in detail in Section 4.8 below. In overview, large machinery was used to recontour the arenas according to the planning map. Berm material was used to infill constructed ponds and to reshape the area. Fill was transported by dumptruck and reworked as necessary by bulldozer. Recontoured areas were ripped (bulldozer) on the contour to minimize sheet and rill erosion. This facilitated natural revegetation by wind dispersed seed and from the seed bank and resulted in a more natural gently uneven roughened surface. To hasten revegetation of the newly constructed areas, native seeds (collected from the local environment), native plant cores (e.g., from rhizomatous species, such as saltgraass, yerba mansa, bulrush, etc.), and pole plantings of woody phreatophytes (e.g., Goodding's willow, seepwillow, Fremont cottonwood) were planted. Hydromulch application was originally considered, but the great success of transplanting and natural regeneration obviated the need for that treatment.

Riparian Revegetation

Native riparian vegetation in the wetland areas around the springs had been largely eliminated or had been degraded by development and livestock grazing. Native riparian vegetation species present in the vicinity of the springs included mesquite, Gooding's willow (*Salix goodingii*), cottonwood (*Populus* sp.), and desert broom (*Baccharis* sp.). Tamarisk and other non-native tree removal was conducted.

The seep and spring complexes were re-vegetated with native, indigenous species and resulted in a plant community structure composed of a grass and forb understory, and a multi-level canopy of cottonwood, Gooding's willow, and desert broom (*Baccharis, spp*.) pole cuttings were collected locally and planted in suitably moist habitats. Cuttings and plugs of graminoid and rhizomatous herb species were installed in moist soils adjacent to spring sources and along waterways created during rehabilitation. Natural seedling establishment of native phreatophyte tree and shrub species (Gooding's willow, cottonwood, seepwillow) were transplanted using pole-planting techniques. Our plantings took place in the spring months, immediately after construction to maximize germination and growth, and to take advantage of residual springtime and monsoon moisture.

The most successful method was to soak cut poles (overnight), debranch them and plant them into deep holes, either dug with auger or iron bar so the pole reached moist soil, or the pole was pushed into mud, and cut with approximately 1-foot exposed, and all exposed cuts were sealed with latex paint to prevent loss of moisture. An alternate and also successful technique of laying poles horizontally in wet soil and covering the majority of the pole was generally done with smaller cuttings that could not be pole planted.

Irrigation

No irrigation system was designed or used.

Non-native species eradication

Non-native vegetation was mechanically removed, and tamarisk was treated with herbicide. Tamarisk and other non-native plant species removal is ongoing.

An attempt to eradicate bullfrogs was made by eliminating habitat that is suitable for bullfrog survival. To date, this has been successful for arenas 1-3. Eradication of bullfrogs and mosquito-fish in arena 4 was conducted with a combination of hunting for bullfrogs as well as a rotenone application. This effort is ongoing.

4 RESULTS AND DISCUSSION

4.1 Summary of results

The goals described by the site rehabilitation plan included rehabilitation of: 1) native riparian vegetation and habitat, 2) hydrologic function; and 3) an ecologically functional pool, channel, and wetland. These goals were oriented towards relieving the springs complex of anthropogenic pressures due to non-native species invasion, and to provide habitat for wildlife, migrating waterfowl, and potentially for species of special concern. The tasks accomplished during the project were appropriately sequenced and effectively set the stage for achieving these goals. The successes exceeded our initial expectations, primarily in the vigorous response of the site both hydrologically and biologically to springflow, once it was released from the pond containments and allowed to emerge on the recontoured, relatively gentle slopes. The return of stream flow to Pakoon Wash, through construction of the outflow from the Arena 4 pond and 4E spring mound, marked the most significant beneficial change. It also highlighted the need to rehabilitate the severely constricted and disconnected channel (relative to its floodplain), resulting from the construction of the agricultural fields, down Pakoon Wash from the pilot project area. The results and discussion for this project are further broken down and documented by arena, starting in Section 4.8.5.

4.2 Land survey maps

The digitally rectified orthophoto contour map of the 56-acre rehabilitation site was developed, (providing 1-foot contours with accuracy: 90% of contours within ½ contour interval and 90% of spot elevations within ¼ contour interval. The map contains 2, 5 and 10’ as well as the 1’ contour lines (Fig. 4-1). The GIS map generated from georeferencing using the land survey shows the site topography and location of significant features (see Figure 4-2). The GIS provided the basis for producing the hydrologic and vegetation maps, as well as the rehabilitation planning maps.

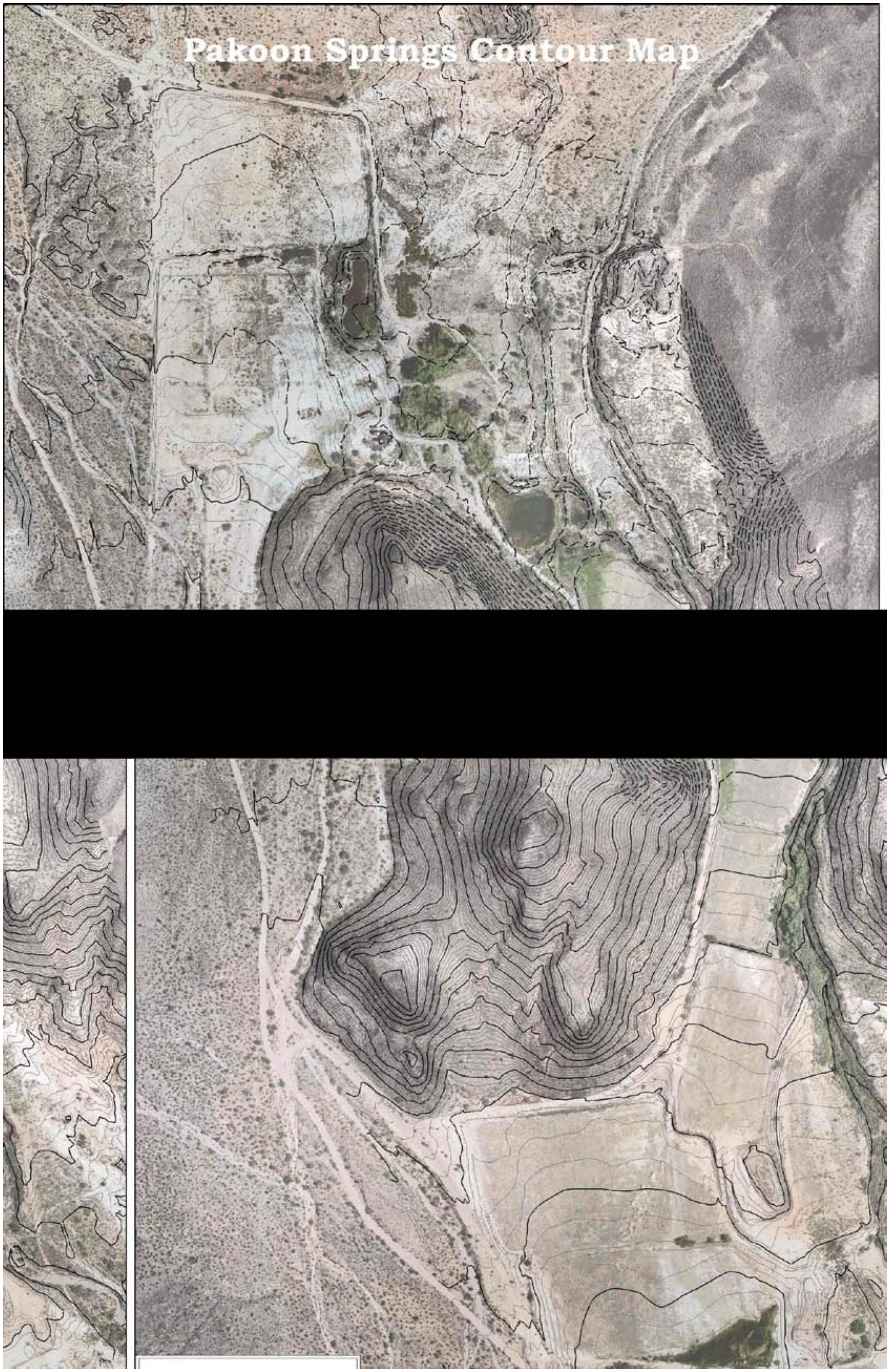


Figure 4-1 Pakoon Springs contour map (pre-rehabilitation)

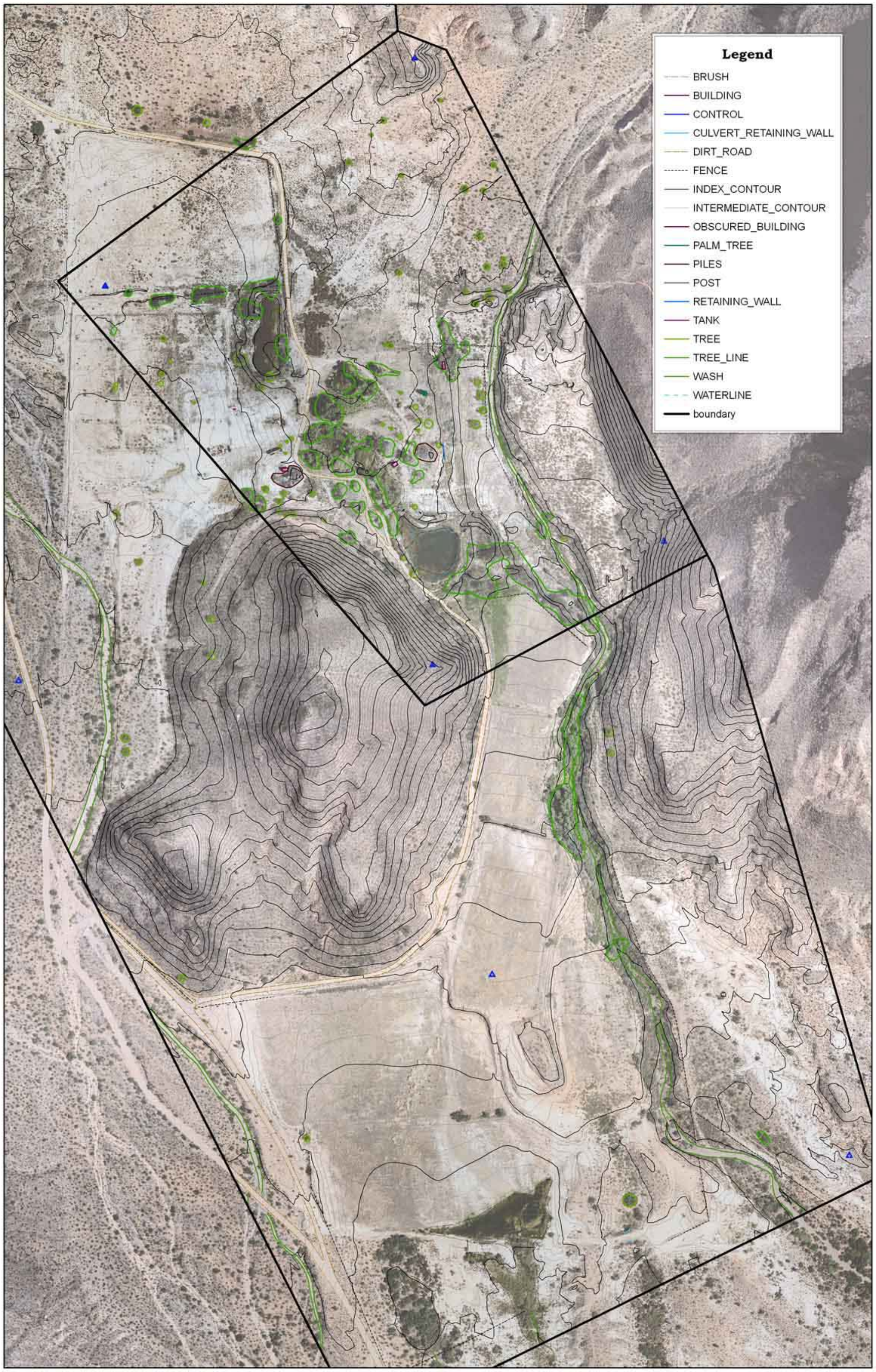


Figure 4-2 Pakoon Springs landscape features

4.3 Soil surveys

4.3.1 Soil cores analysis

Fifty-six 1.5-in-diameter soil cores (1/acre) up to 5 ft (1.524 m) in depth were measured for soil characteristics including, soil moisture, soil type, color, pH, and soil salinity (Table 7-1). All soil core data collected were included as layers in the Pakoon Springs GIS map (see Fig. 2-2).

Soil texture: Surface soil textures throughout the agricultural fields and springs areas were fine-grained silt-clay and highly disturbed by anthropogenic activities to depths of up to 0.5 m. Soils of the stream channels and basalt flow-dominated slopes varied in texture from fine-grained silt-sand to coarse-grained cobble or breccia to bedrock (Appendix 7.4.2).

Soil moisture: Percent soil moisture ranged from 0 to 93%, and averaged 12.1% (1 sd = 17.6, n = 98; Appendix 7.4.2).

Soil type (color): The soils sampled by coring at Pakoon Springs were, on average brown-black, pale, pale buff-orange in color. Munsell color hues of YR (yellow-red), varying in hue number from 2.5 (black-gray-coral) to 10 (dark brown-pale gray-buff yellow), with an average of 6.3 (1 sd = 1.87; n = 145; Table 4-1). Soil color values varied across the study area, ranging from 4 to 8, and averaging 5.9 (1 sd = 0.82, n = 145; Table 4-1; Appendix 7.4.2). Soil color chroma values varied across the study area, ranging from 1 to 4, and averaging 3.1 (1 sd = 0.87, n = 145; Table 4-1; Appendix 7.4.2).

Soil pH: Soil pH varied to some extent across the study area, ranging from 7.71 to 9.79, averaging 8.5 (1 sd = 0.4, n = 145; Table 4-1; Appendix 7.4.2). These pH values for soils are characteristic of those in carbonate- and karst-dominated springs soils and alluvium, and are not likely to influence rehabilitation planning.

Soil salinity: Soil salinity varied greatly across the study area, ranging from 22 to 12,700, and averaging 978.6 ppm (1 sd = 1588.35 ppm, n = 145; Table 4-1; Appendix 7.4.2). These salinity values were consistent with carbonate-dominated and relatively highly mineralized soils and possibly repeated precipitation events.

Soil groundwater: No groundwater was detected at any of soil core sampling sites. Three sites containing surface water were encountered during soil core sampling. Average pH of these three soil samples was 7.3 (1sd = 0.19); average temperature of these samples was 12.4 (1 sd = 1.41)^{o}C, primarily influenced by air temperature; and average salinity of these samples was 580.0 ppm (1 sd = 240.58 ppm), commensurate with the surface water quality characteristics reported in section 4.4 (Appendix 7.4.2).

Table 4-1 Soil characteristics of Pakoon Springs Rehabilitation project area, January 2008.

Statistic	Hue	Hue No.	Value	Chroma	pH	Salinity (ppm)
Mean	YR	6.3	5.9	3.1	8.5	978.57
N	145	145	145	145	145	145
Std	---	1.87	0.82	0.87	0.4	1588.35
Minimum	YR	2.5	4	1	7.71	22
Min. Color	YR	Dark	Red	Brown	---	---
Maximum	YR	10	8	4	9.79	12700
Max. Color	YR	Medium	Orange	Brown	---	---

N = number of samples**, Std =** standard deviation

4.3.2 Discussion

The surficial geology and soils of Pakoon Springs 56 acre site have been highly modified by human activities. All of the low-gradient surfaces have been disturbed to a depth of at least 20-50 cm, and in and around springs sources the depth of human disturbance may exceed 3 m. Soils coring data gave little insight into the long-term history of the site, insight can only be determined from detailed analysis of soils from a suite of strategically located trenches across the site. Springs soils are dominated by groundwater discharge deposits commonly of carbonate lithology, in addition to igneous and sedimentary-derived silts and clays, with moderate to slightly alkaline pH, and variable salinity. Desert wash channel and terrace soils are dominated by sands and gravels, with some boulders, while basalt slope soils are generally gravelly with a preponderance of large boulders or bedrock. Despite the extent of alteration, the surficial soils of the Pakoon Springs 5 – 10 acre rehabilitation site appeared capable of supporting the native plant species that were proposed for planting. Feedback of vegetation into pedogenesis at the rehabilitation site is likely to require decades to centuries and the geomorphic rehabilitation of the site has set the stage for future soil development.

4.4 Hydrological surveys

Hydrologic field monitoring for Pakoon Springs began in August 2006 with hydrologic elevation control establishment at the ten water features that had current or historical hydrologic significance (see Fig. 2-2, Table 7-2). These locations were incorporated onto the land survey map and helped establish a potentiometric water surface elevation for the historic water features within the main spring area. The water surface elevations were also incorporated into rehabilitation spring outflow planning.

In July 2007 water survey monitoring at Pakoon Springs was initiated. This included water-quality field measurements and estimates of spring discharge. Physical measurement(s) of groundwater discharge from the numerous seeps and springs in the Pakoon Springs area prior to rehabilitation was difficult. This is due to the ever-increasing amount of vegetation that covers most available spring discharge. Where an open-channel surface discharge is available conditions do not always lend themselves to determining a reproducible flow measurement. However, measured estimates of spring discharge were made at three locations within the Pakoon Springs area. It is noteworthy that subsequent to July 2007, in particular after rehabilitation, additional measurement locations were discovered that appear to have contributed to increased total discharge estimates (Fig. 4-3, Appendix 7.4.1).

In January 2008 water survey monitoring continued with field measurement locations similar to July 2007 and a few new measurement locations included (Fig. 4-3, Appendix 7.4.1). Subsequent to spring rehabilitation, that began in the Spring 2008 – early Fall 2008, water survey monitoring in both April 2008 and July 2008 revealed water sources that had previously been unknown or hidden. These previously unknown and hidden sources have led to more accessible measurement locations and reproducible field measurements. Not surprising, there continue to be instances where seeps or springs have emerged in areas that were previously dry months before. As rehabilitation efforts continued to reshape channel configurations new discharge locations emerged in July 2009 and this allowed for portable parshall flume measurements from the largest spring discharge source at Pakoon Springs (Arena 4).

In January 2010 water survey monitoring continued and some monitoring points remained unchanged, however others were becoming difficult to access due to successful rehabilitation vegetation growth. As a result of vegetation growth some monitoring points would be moved slightly (5 -15 feet) or some eventually became inaccessible.

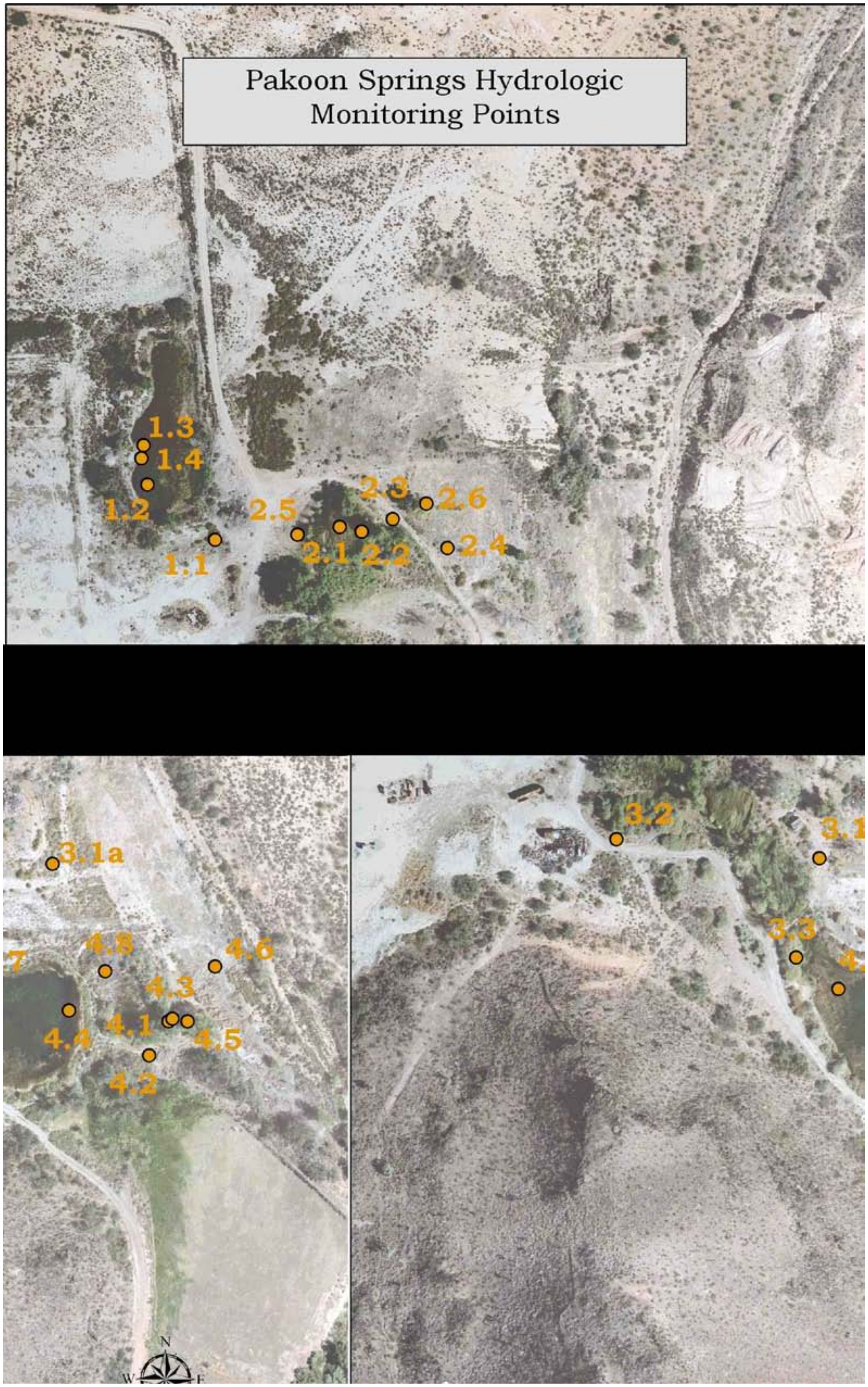


Figure 4-3 Hydrological monitoring points, see Table 7-2 for gps locations of points

4.4.1 Discharge measurements

The flow measurements monitored for Pakoon Springs are compared to historic discharge measurements and estimates in Table 4-2.

Table 4-2 Pakoon Springs discharge measurements comparison of years between 1976 and 2010. Refer to Appendix 7.4.1 for detailed discharge results.

Date	Measured Discharge (gpm)	Comments
1976	130*	USGS
Pre 1984	58.2**	BLM
07/20/07	11.0	GCWC
01/15/08	67.0	GCWC
04/29/08	81.8	GCWC, post rehabilitation
07/15/08	84.5	GCWC, post rehabilitation
02/26/09	82.4	GCWC, post rehabilitation
07/30/09	76.4	GCWC, post rehabilitation
10/16/09	86.7	GCWC, post rehabilitation
03/08/10	96.7	GCWC, post rehabilitation
08/19/10	74.2	GCWC, post rehabilitation

* estimated discharge ** prev. measured discharge

The disparity in discharge measurements shown in Table 4-2 is evident and could be an artifact of measurement technique, vegetation cover, time of year, actual discharge, or other factors. In addition, during the modern history of development at Pakoon Springs there have been untold quantities of unmapped and non-engineered underground pipes that conveyed spring water to various regions of the property. The condition, locations, size, and amounts of discharge associated with the piping network is unknown and probably contributed to the variation in discharge estimates that are apparent prior to April 2008 (pre rehabilitation discharge measurements). During rehabilitation efforts most if not all of the historic piping network was dismantled. There remains the slight possibility that some of the piping network remains, however that flow would probably be either measured at one of the monitoring points or consumed by existing vegetation.

Reduced discharge measurements recorded in July 2009 and August 2010 appear to reflect vegetation growth (and the success of rehabilitation) at all of the Arenas during and after rehabilitation efforts were generally complete. Conversely, the July 2008 discharge, which is greater than 2009 and 2010 measurements, probably does not reflect the same amount of discharge being consumed by vegetation as seen in 2009 and 2010, and this is probably an artifact of the July 2008 measurement being at the beginning phase of rehabilitation and new vegetation growth. The higher fall and winter discharges recorded in October 2009 and March 2010 probably reflect the limited moisture requirements of dormant vegetation, thus there is less of the springs discharge being consumed during these times of the year.

Although riparian vegetation growth/expansion was one of the goals of Pakoon Springs rehabilitation there has been such success that vegetation overgrowth has reduced the ability to measure discharge in areas that were previously accessible. As a result and as shown in

Appendix 7.4.1, discharges from most measurements points are reduced or are unobtainable during the summer months, however to date these measurement points have been accessible in the fall, winter, and spring months. Access to measurement points could change in the future.

4.4.2 Field water quality

Current field water-quality measurements for Pakoon Springs are compared to historic water quality measurements in Table 4-3.

Table 4-3 Pakoon Springs historic comparison of electrical conductivity (EC), temperature and pH field measurements. Refer to Appendix 7.4.1 for detailed field water-quality results.

Date	Spring measurement			Air Temp C°	Source	Comments
	ECμM/cm @25C°	Temp C°	pH			
1976	455	n/a	n/a	n/a	USGS	Unknown measurement location
Pre-1984	500	n/a	n/a	n/a	BLM	Unknown measurement location
05/20/00	491	29.8	6.94	20.6	GCWC	Orifice measurement, Arena 2
07/20/07	481	26.2	7.28	40.6	GCWC	Pool measurement, Arena 2
01/15/08	466-557	12.1-28.9	6.6-6.8	12.2-16.1	GCWC	Pre-rehabilitation, numerous locations
04/29/08	428-2,034	20.4-30.2	6.4-7.8	23.3-31.1	GCWC	Post-rehabilitation, numerous locations
07/15/08	429-1,660	29.7-35.9	7.3-7.9	26.1-37.8	GCWC	Post-rehabilitation, numerous locations
02/26/09	409-1,109	12.1-28.2	6.7-8.2	10.5-23.4	GCWC	Post-rehabilitation, additional locations
07/30/09	429-820	21.2-31.7	6.6-8.2	22.2-39.4	GCWC	Post-rehabilitation, additional locations
10/16/09	432-940	21.3-30.2	7.3-8.7	24.4-33.9	GCWC	Post-rehabilitation, numerous locations
03/08/10	460-1,443	14.4-29.2	7.0-8.2	11.1-18.0	GCWC	Post-rehabilitation, numerous locations
08/19/10	445-888	24.5-31.9	7.2-7.8	25.0-38.9	GCWC	Post-rehabilitation, numerous locations

The variability of field water-quality results is readily apparent from measurements recorded. Each arena appears to have unique physical conditions attributable to their variable water quality range throughout Pakoon Springs (Appendix 7.4.1).

Summary results on Table 4-3 show lower electrical conductivity values in the summer months of July 2009 and August 2010 as compared to the spring month of March 2010 (Appendix 7.4.1). These variabilities in water quality appear similar to the cycle of changes in discharge results for summer vs. winter months. Recall that prior to July 2009 rehabilitation growth was beginning and vegetation was not well established, therefore after revegetation and rehabilitation there could be stability in the cycle of water quality changes. Furthermore, the changes in water quality generally parallel changes measured in discharge with lower discharges in July 2009 and August 2010 appearing to coincide with to lower electrical conductivity measurements and higher pH values in July 2009 and August 2010. It is important to note that this is a limited data set and therefore additional measurements would be necessary to confirm this preliminary interpretation.

4.4.3 Laboratory water quality

Water samples were collected from three Arenas (Arenas 2, 3, and 4) with varied discharge and water quality characteristics (Table 4-4).

Laboratory water-quality analytical samples were collected by GCWC in 2000 and those results are presented in Table 4-4 along with the most recent laboratory results collected in July 2008 and March 2010 (Appendix 7.4.1). Similar to field water-quality measurements there is variability between the different Arenas' laboratory analytical results measured in 2008. Again, each Arena appears to have unique physical conditions that contribute to the variable water quality range between Arenas at Pakoon Springs. The laboratory results indicate that Arena 4 (the pond) has the lowest total dissolved solids (TDS) concentration and Arena 3 has the highest TDS concentration. Field water-quality results show a similar water quality result as the TDS values where electrically conductivity results are lowest for Arena 4 and highest for Arena 3. Sulfate concentrations are noteworthy as the high discharge locations of Arena 4 and the year 2000 Arena 2 results have the lowest sulfate values and Arenas 2.3 and 3.1 with lower discharges valves have higher sulfate concentrations. This suggests a higher resonance time, probably originating from the fine grain sediments near the surface, for the lower discharge springs at Arenas 2 and 3.

Stable isotope results from 2000 and 2010 are approximately similar and suggest the water source has a component of regional groundwater and/or high elevation recharge. This could equate, for example, to a possible Virgin Mountains or Pleistocene (old) water source. Additional data would be required in the region to determine a potential groundwater source for Pakoon Springs.

Table 4-4 Laboratory water-quality analytical sample results (Appendix 7.4.1).

Location	Date	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	SO4 mg/L	HCO3 ALK mg/L	CaCO3 ALK mg/L	NO3 mg/L	NH3 mg/L	PO4 mg/L	TDS* mg/L	TDS** mg/L	$d^{18}O_V$ SMOW	dD_V SMOW
Arena 2 (orifice)	05/20/00	99.2	19.0	18.0	13.0	57.2	50.3	185	152	0.8	0	0	442	348	-13.51	-102.9
Arena 2.3 (north)	07/15/08	66	25	34	11	4.3	148	200	164	0.293	ND	ND	488	387	na	na
Arena 3.1 (east)	07/15/08	73	38	95	41	24	317	180	148	0.0540	ND	ND	768	676	na	na
Arena 4 spring box	07/15/08	40	18	24	8.1	4.84	78.6	150	123	0.328	ND	ND	324	247	na	na
Arena 4.7	03/08/10	na	na	na	na	na	na	na	na	na	na	na	na	na	-13.94	-102.48

* sum of cations and anions

** sum of cations and anions with bicarbonate calculated by multiplying by 0.4916 to make comparable to residual upon evaporation

ND = non-detectable (below detection limits)

NA = not analyzed

4.4.4 Additional hydrologic features

A water well was discovered on the north edge of the Pakoon property. This well is constructed with 16-inch diameter steel casing and has an existing 4-inch pump column set within the steel casing. The pump is not functional although it may have been able to produce a typical domestic instantaneous discharge rate of approximately 5 gpm. In all likelihood this rate probably was not maintained for any length of time. This interpretation is based on the fine grained sediments that the well appears to have encountered during construction. Depth to water measurements from the well are included in Table 4-5.

Table 4-5 Pakoon Springs well water-level measurements.

Date	Depth to water (ft)*
082606	12.60
072007	12.75
011508	12.63
042908	12.23
071508	12.45
022609	12.03
073009	12.17
101609	12.13
030810	12.15
081910	11.95

* Measurement point is the top of the casing.

Evidence for paleodischarge is suggested by ground-water discharge deposits in the form of travertine. These deposits are located in the wash northeast and east of the main springs area. The geomorphology of the spring area suggests that prior to modern development Pakoon Springs had a spring mound character with the discharge direction probably somewhat similar to that following development, but with flow to the west curtailed by drainage alteration. Based on the presence of travertine deposits in Pakoon Wash, surface discharge from the springs likely reached the wash east and southeast of the main springs area, creating a perennial or largely perennial stream. An additional groundwater flow component probably emerged at the northernmost discharge area of Arena 1 (and Arena 3) and a small portion of overall Pakoon Springs flow was discharged to the west (Fig. 3-1). However the definitive areal extent of historic spring discharge for Pakoon Springs remains unknown.

4.4.5 Discussion and rehabilitation implications

Spring flows for Pakoon Springs have sustained varied discharge from 76 gpm to 97 gpm based on measurements after rehabilitation began. Pakoon Springs water chemistry appears to represent the natural groundwater/spring system with limited influence from spring manipulation. Variations in water chemistry appear to have minimal affects and are compatible with the vegetation community. Therefore, rehabilitation of Pakoon Springs has been focused on geomorphic configuration and vegetation distribution, rather than pollution abatement. The presence of carbonate terraces along Pakoon Wash indicate that Pakoon Springs was at least occasionally a perennial stream in Holocene times. Redirecting flow to Pakoon Wash, therefore, became a relatively high priority for this project. Total outflow of Arenas 3 and 4 was less than 70 gpm (4 L/s), prior to site revegetation, however little of this outflow reached Pakoon Wash.

4.5 Vegetation surveys (pre-reconstruction)

4.5.1 Analyses

Mapped vegetation polygons were incorporated into the project GIS and the polygons were described on the basis of structure, formations, and plant series and associations (Figs 4-4 and 4-5, Table 4-6 and appendices referenced below). We followed the vegetation classification terminology of Brown (1994) for the greater Southwest, a system which is largely consistent with prior and adjacent vegetation mapping of Grand Canyon National Park (Warren et al. 1982), and with the North American vegetation classification system. Polygon area was determined from the GIS and for ease of the rehabilitation planning was reported in English units.

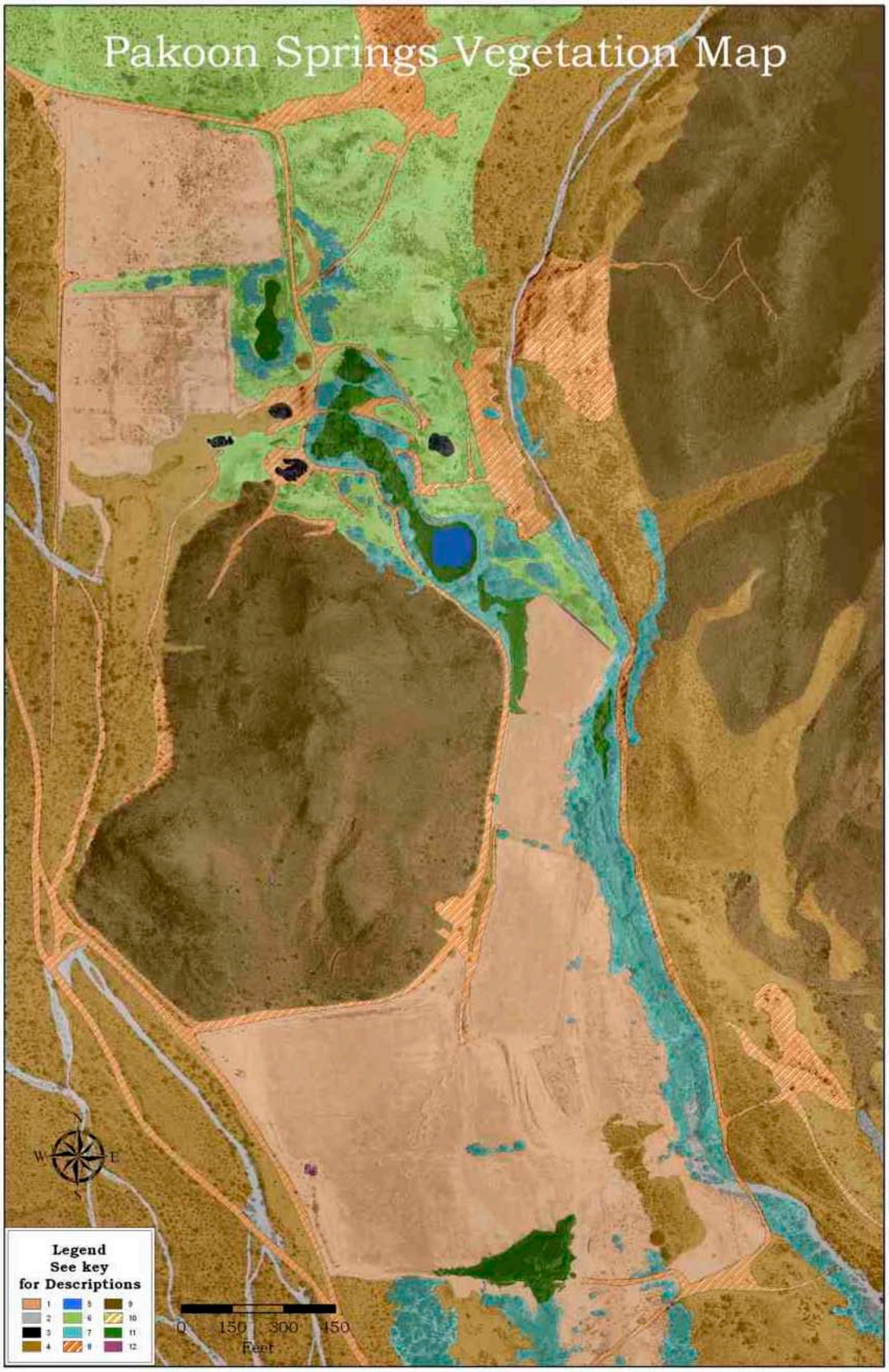


Figure 4-4 Vegetation map, prior to rehabilitation

Figure 4-5 Vegetation map color key

Table 4-6 Vegetation map key

ID	Description	Area	Acres	Hectares
1	Agricultural Field	1860474.87	42.71	17.28
2	Arroyo	167046.98	3.83	1.55
3	Junk Pile	12407.63	0.28	0.12
4	Low Gradient Desert Scrub	3100484.09	71.18	28.80
5	Open Water	12134.44	0.28	0.11
6	Paleospring Scrub	1089101.00	25.00	10.12
7	Riparian	591106.45	13.57	5.49
8	Road	739405.58	16.97	6.87
9	Rocky Slope	2888643.74	66.31	26.84
10	Trail	3944.67	0.09	0.04
11	Wetland	139572.56	3.20	1.30
12	Undefined	4494.25	0.10	0.04

4.5.2 Plant diversity

To date, we have detected a total of 64 plant species on and around the immediate vicinity of Pakoon Springs. We detected 1 nonnative aquatic species, 15 native and 11 nonnative species that function as ground covering taxa, 32 native and 3 nonnative shrub species, 2 native and 1 nonnative species that attain middle canopy stature (4-10 m tall), and 2 native species that achieve tall canopy stature (>10 m tall; Appendix 7.4.3). Thus, a total of 16 (25%) of the plant species at the Pakoon Springs site were non-native. Several non-native species at the site have been eradicated, including *Tamarix* spp. and date palm (*Phoenix dactylifera*), however these species resprout and ongoing maintenance is required. Only one tree species (*Salix gooddingii)* appears to be indisputably native to the site. Although Fremont cottonwood (*Populus fremontii*) is native in the immediate region, our interviews with the previous owner and their locations near the old house sites indicated that it may not be native to the site, and was perhaps introduced for shade or ornamental purposes.

4.5.3 Vegetation classification

Using Brown's (1994) classification terminology and numbering system, we mapped a total of 79 polygons at the Pakoon Springs rehabilitation site (Table 7-3, Appendix 7.4.3). Visually estimated vegetation cover data on these polygons are presented in Appendix 7.4.3.

We condensed these polygons into 11 land cover types, including vegetation-defined, physically defined (i.e., open water, arroyo channel), and anthropogenic surfaces (roads, trails, buildings, debris piles, etc.; Table 4-7, Figure 4-6). These data demonstrate that the site supports peripheral rocky slope and low gradient desertscrub (largely *Larrea divericata-Ambrosia dumosa*, and

Yucca brevifolia, totaling 15.0 ac (26.8 percent) and dysclimax agricultural fields habitat (9.0 ac, 16.1 percent), with considerable cover by paleospringmound shrublands (dominated by jimmyweed AKA goldenweed -- *Isocoma acredius*; 13.1 ac, 23.5 percent). The site presently supports 9 ac (16.1 percent) desert riparian habitat, and 2.3 ac (4.0 percent) of springs wetland habitats.

4.5.4 Rare plants search

We analyzed our field data and species lists to determine whether any of those species were likely to occur at Pakoon Springs, finding no evidence of listed species at the site thus far (Table 4-7 and Table 4-8).

4.5.5 Cover types and implications for rehabilitation

We quantified the extent of direct anthropogenic alteration of Pakoon Springs to contribute to rehabilitation planning of the site. Careful assessment of site geomorphology, soils, and vegetation types supported the premise that prior to settlement and alteration, Pakoon springs likely consisted of several low- gradient wet cienega or hillslope springs perhaps with some limnocrenic habitat (*sensu* Springer et al. 2008) with at least four aggregations of emergent flow, at least one springs pool, and a small perennial stream.

Rehabilitation needs therefore focused on four habitat types: rocky hillsides, desert riparian, peripheral paleospring riparian shrublands, and spring-fed wetlands. Below we describe the characteristics of the vegetation-defined polygons and implications that applied to their rehabilitation.

Desert Scrublands: This assemblage occurs on the rocky basalt talus hillsides around Pakoon Springs. The desert vegetation surrounding Pakoon Springs consists of Warm Temperate Desertlands formations, dominated by the Creosote bush series (primarily the *Larrea divaricata-Ambrosia dumosa* association) and the Catclaw series (primarily the *Acacia greggii*-mixed scrub association). In addition, the site falls at the lower elevation limit of the Joshua tree series (primarily the *Yucca brevifolia-Larrea divericata* association). We grouped these associations as low gradient or rocky slope desertscrub.

Although exposed to long-term grazing by cattle and feral burros, the rocky hillsides around Pakoon Springs are relatively intact, and are relatively protected from further grazing impacts by the new fencing. Full recovery of that habitat from overgrazing is likely to require centuries; however, that habitat is in relatively stable and improving condition, and the costs of revegetation of that habitat are prohibitive. If protected from fire and further human alterations, the desert habitat at the Pakoon Springs site may serve as a useful control against which to measure changes in other nearby desert habitats. In addition, the surrounding desert uplands are providing sources of propagules for on-going colonization of the agricultural fields and former agricultural terraces.

Desert Riparian Woodland-Forest: Desert riparian habitat occurs in the washes, surrounding the springs, and in scattered clumps of catclaw and mesquite in agricultural fields, likely related to stringer riparian habitats that predate settlement. Desert riparian woodland-forest vegetation at Pakoon Springs include Warm Temperate Swamp and Riparian Forest formations, dominated by the Cottonwood-Willow association (*Populus fremontii-Salix gooddingii* series (although we believe that Fremont cottonwood has been introduced to the site) and the Tropical-Subtropical Swamp and Riparian Scrub formation (dominated by the *Prosopis pubscens – Prosopis glandulosa – Pluchea sericea* series). In addition, Warm Temperate Mohavian Interior Strand associations include the Mixed Scrub Series (dominated by deciduous *Tamarix*-mixed shrub association; however, by the time of this report *Tamarix* had been removed from the site). This determination varies somewhat from Warren et al's (1982) classification of riparian vegetation in adjacent Grand Canyon as being primarily Strandline Formation series. Their description of the dominance of strandline habitat as riparian habitat in Grand Canyon was due, in part, to the general absence of gallery forest along the flood-scoured Colorado River.

As desert riparian habitat, we suspect that the largest honey mesquite and catclaw plants are likely to be original, pre-settlement plants. Those species at this site are heavily infested with California mistletoe (*Phoradendron californicum*). Mistletoe infestation may be related to the stresses of altered (included augmented) surface flow and browsing by cattle and feral burros. While dendrochronological analysis of those plants would be interesting, the likelihood of readable rings on both species is low, due to spiral growth patterns. However, radiocarbon dating might provide approximate ages of those plants, if such information is needed to improve rehabilitation planning and site management. Therefore, as these older trees die, it may be useful to collect and keep slabs of stems for radiometric dating purposes. Such slabs should be collected low on the plants, georeferenced, labeled carefully as to date, and stored in a cool, dry environment for analysis and dating.

We believe the oldest Goodding's willow trees on the site are original, likely pre-dating settlement. Although dendrochronology may provide over time insight into changing flow and even geochemistry, heart rot generally precludes dendrochronologic analysis of large old Goodding's willows (e.g., Mast and Waring 1996). . While native to the region, we believe the Fremont cottonwood trees at the site are non-local in origin; however, their tall canopy structure makes them of considerable importance to neotropical migrant birds and other wildlife. We successfully planted some cottonwood poles for habitat development and landscape stabilization, and we observed vigorous cottonwood seedling establishment in several arenas. Fremont cottonwood is likely to prosper at the site, and provides additional habitat structure.

Paleospring Riparian Shrublands: The paleosprings mound vegetation occurs on fine-grained clay and silt substrates, at relatively low gradients surrounding Pakoon Springs. Geomorphology and groundwater supplies feeding these shrublands have been strongly altered by diversion, housing construction, and cattle and ostrich ranching activities. This habitat is strongly dominated by native jimmyweed (goldenweed), with some quailbush (*Atriplex lentiformis*), inkweed (*Sarcobatus vermiculatus*), and in wetter places, saltgrass (*Distichlis spicata*). Reconstruction of the habitat allowed these species to recolonize from the remaining populations relatively quickly, and the densities of some species, such as jimmyweed, continue to increase as appropriate to the level of natural drought stress on the fine, clay soils that dominate these microhabitats. Augmented reseeding enhanced recolonization by several shrub species, and was of some value in achieving appropriate densities. We observed a great increase in Atriplex elegans establishment in 2010. This native annual herb covered most of the disturbed land surrounding the treated arenas. Overall, we recommend that seeds of these and other native plant species be collected on and near the Pakoon site as they become seasonally available, and that this native seed be used to replant this and other spring mound habitats in the region.

Springfed Wetlands: Wetland vegetation at Pakoon Springs consists of Marshland Formation including Tropical-Subtropical Marshland - Sonoran Interior Marshland Series, dominated by Cattail (*Typha domingensis* Association), Bulrush (*Scirpus* (now *Schoenoplectus) americanus* Association), and Mohavean Interior Marshland – Saltgrass Series (dominated by the *Distichlis stricta* -- and including *Anemophila californica* -- Association).

Wetland vegetation occurs on deep peat beds at Pakoon Springs, indicating long-term (at least mid-late Holocene) existence of springfed wetlands habitat at the study site. Wet vegetation is presently strongly dominated by cattail, a native, but highly invasive species that likely will cause perennial management concern. We recommend that the BLM focus its revegetation efforts primarily on bulrush, spikerush, *Anemophila*, and saltgrass, and limit construction of additional cattail habitat to the extent possible. This emphasis, and the above discussion of desert riparian vegetation, likely will prove most effective in improving conditions for wildlife, and will minimize the need for future habitat maintenance actions.

Agricultural Fields: Agricultural fields dominate the Pakoon Spring landscape, as largely barren, heavily modified desertscrub and paleospring shrublands. Soil textural variability has been reduced to silt-clay on these surfaces, and they are dominated by weeds. Gradual colonization by native desertscrub is occurring on these surfaces, with more intensive colonization along the margins. Under appropriately wet conditions, reseeding these surfaces with native desertscrub species may be the most effective way to revegetate these surfaces. In addition, increasing the gradient and restoring soil textural complexity is likely to enhance native revegetation; however, recovery of these surfaces to near-natural conditions is likely to require centuries.

4.5.6 References cited

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4.5.7 Summarized data

Table 4-7 Native and non-native vascular plant species detected at Pakoon Springs. (Stratum SC = shrub cover, GC – ground cover, MC = middle canopy cover, AQ = aquatic)

Plant Species	Stratum	Nativity
Acacia greggii	SC	Native
Ambrosia dumosa	SC	Native
Anemopsis californica	GC	Native
Atriplex canescens	SC	Native
Atriplex confertifolia	SC	Native
Atriplex elegans	GC	Native
Atriplex lentiformis	SC	Native
Baccharis emoryi	SC	Native
Baccharis salicifolia	SC	Native
Baileya sp.	GC	Native
Bassia sp.?	GC	Nonnative
Brassica sp.?	GC	Nonnative
Bromus rigidus	GC	Nonnative
Bromus rubens	GC	Nonnative
Bromus sp.	GC	Nonnative
Cylindropuntia bigelovii	SC	Native
Cynodon dactylon	GC	Nonnative
Datura wrightii	SC	Native
Distichlis spicata	GC	Native
Echinocereus triglochidiatus	SC	Native
Eleocharis nr. Palustris	GC	Native
Encelia farinose	SC	Native
Ephedra sp.	SC	Native
Eriogonum sp. (annual)	GC	Native
Ferocactus cylindraceus var. cylindraceus	SC	Native
Festuca sp.	GC	Nonnative
Grindelia sp.?	GC	Native
Gutierrezia sp.	SC	Native
Helianthus annuus?	GC	Native
Heliotropium curassavicum	GC	Native
Hymenoclea sp.	SC	Native
Isocoma acradenia	SC	Native
Krameria erecta	SC	Native
Larrea tridentate	SC	Native
Lycium sp.	SC	Native
Melilotus sp.	GC	Nonnative
Morus sp.	SC	Nonnative
Nicotiana obtusifolia	GC	Native
Nymphaea odorata	AQ	Nonnative
Opuntia basilaris	SC	Native
Opuntia phaeacantha	SC	Native
Opuntia sp (Platyopuntia)	SC	Native
Phoenix dactylifera	MC	Nonnative
Phoradendron californicum	SC	Native
Pleuraphis jamesii?	GC	Native
Pluchea sericea	SC	Native
Populus fremontii	MC	Native
Prosopis glandulosa	SC	Native
Prosopis pubescens	SC	Native

Punica granatum	SC	Nonnative

Table 4-8 Rare or listed plants on or in the vicinity of Pakoon Springs.

Rare or Listed Plant Species	Status
Arizona cliffrose (Purshia subintegra)	E
Alcove bog orchid (Platanthera zothecina)	SC, S2
Arizona leather flower (Clematis hirsutissima var. hirsutissima)	---, S2
Atwood wild buckwheat (Eriogonum thompsonae var. atwoodii)	SC, S1
Beath milkwetch (Astragalus beathii)	---, S2
Black Rock daisy (Townsendia smithii)	---, S1
Brady pincushion cactus (Pediocactus bradyi)	E
Cliff milkvetch (Astragalus cremnophylax var. myriorrhaphis)	SC, S1
Crevice (Sheep Basin) beardtongue (Penstemon petiolatus)	---, S1
Deer Creek agave (Agave phillipsii)	Endemic in GC
Diamond Butte milkvetch (Astragalus toanus var. scidulus)	---, S1
Dwarf bear-poppy (Arctomecon humilis)	E
Fickeisen (Plains) pincushion cactus (Pediocactus peeblesianus var. fickeiseniae)	C, S1S2
Flagstaff pennyroyal (Hedeoma diffusum)	Endemic, S3
Frazier's Wells wild buckwheat (Eriogonum ripleyi)	SC, S2
Grand Canyon catchfly (Silene rectiramea)	SC, S1
Grand Canyon rose (Rosa stellata ssp. abyssa)	SC, S2
Heliotrope milk-vetch (Astragalus montii)	T
Holmgren milkvetch (Astragalus holmgreniorum)	PE, S1
House Rock fishhook cactus (Sclerocactus sileri)	---, S1
Jones cycladenia (Cycladenia humilis var. jonesii)	T
Kaibab bladderpod (Lesquerella kaibabensis)	SC, S1S2
Kaibab paintbrush (Castelleja kaibabensis)	---, S2
Kodachrome bladderpod (Lesquerella tumulosa)	E
Las Vegas bearpoppy (Arctomecon californica)	SC, S2
Maguire daisy (Erigeron maguirei)	T
Marble Canyon dalea (Psorothamnus arborescens)	---, S2
Marble Canyon milkvetch (Astragalus cremnophylax var. hevronii)	---, S1
McDougall's flaveria (Flaveria mcdougallii)	---, S2
Mohave panicum (Panicum mohavense)	---, S1
Morton wild buckwheat (Eriogonum mortonianum)	SC, S1
Mt. Trumbull beardtongue (Penstemon distans)	S1, S2
Navajo phlox (Phlox cluteana)	---, S2
Navajo sedge (Carex specuicola)	T
Painted Desert milkvetch (Astragalus sophoroides)	---, S2
Paradine (Kaibab) pincushion cactus (Pediocactus paradinei)	SC, S2
Parish scorpionweed (parishii)	---, S1
Peebles Navajo cactus (Pediocactus peeblesianus var. peeblesianus)	E
Roaring Springs prickly poppy (Argemone arizonica)	SC, S1
Ross spurge (Euphorbia aaron-rossii)	Endemic, S1
San Francisco Peaks groundsel (Senecio franciscanus)	T
Sentry milk-vetch (Astragalus cremnophylax var. cremnophylax)	E

Siler pincushion cactus (Pediocactus sileri)	T
Slender evening primrose (Camissonia exilis)	SC, S1
Sticky buckwheat (Eriogonum viscidulum)	SC, S1
Three-heart (Tricardia watsonii)	---, S2
Tusayan flame flower (Talinum validulum)	SC, S3
Ute ladies'-tresses (Spiranthes diluvialis)	T
Virgin thistle (Cirsium virginense)	SC, S1
Welsh's milkweed (Asclepias welshii)	T

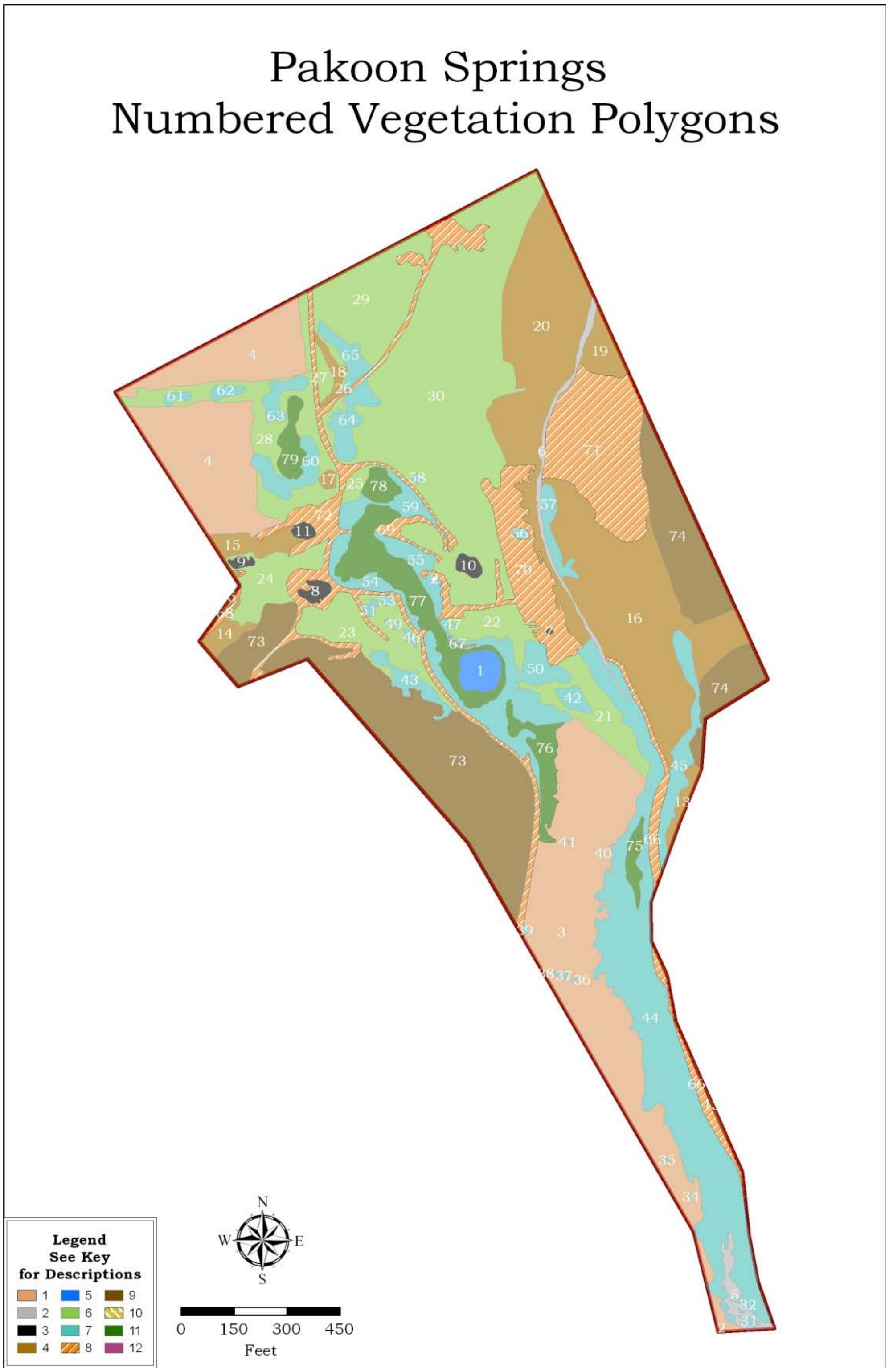

Figure 4-6 GIS map of the 56-acre rehabilitation site, with vegetation polygons (see Table 7-3). Key: 1 –old agricultural fields (scraped and leveled), 2 – arroyo channel, 3 – debris (junk) pile, 4 – low gradient desertscrub, 5 – open water, 6 – paleosprings riparian shrublands, 7 – desert riparian woodland-forest, 8 – road or scraped areas, 9 – rocky slope desertscrub, 10 – tracks, 11 – wetlands.

Table 4-9 Summary of cover types mapped at Pakoon Springs, and their total area.

ID	Cover Type	Total Area (ac)	Percent
1	Agricultural Fields	8.968	16.01
2	Arroyo Channel	0.512	0.91
3	Junk Pile	0.285	0.51
4	Low Gradient Desertscrub	8.335	14.87
5	Open Water	0.279	0.50
6	Paleospring Shrublands	13.145	23.46
7	Riparian Phreatophyte Vegetation	9.030	16.12
8	Roads, Trails, and Non-agricultural Graded Lands	6.537	11.67
9	Rocky Desert Slope	6.679	11.92
10	Roads/tracks	0.004	0.01
11	Wetlands	2.259	4.03
	Total	56.032	100.00

4.6 Photodocumentation

General site photographs were taken using a Konica Minolta DiMage Z2 (4.0 megapixel) digital camera with a 10X zoom. All monitoring photos were taken without zoom. Photo monitoring locations are shown in Fig. 4-7.

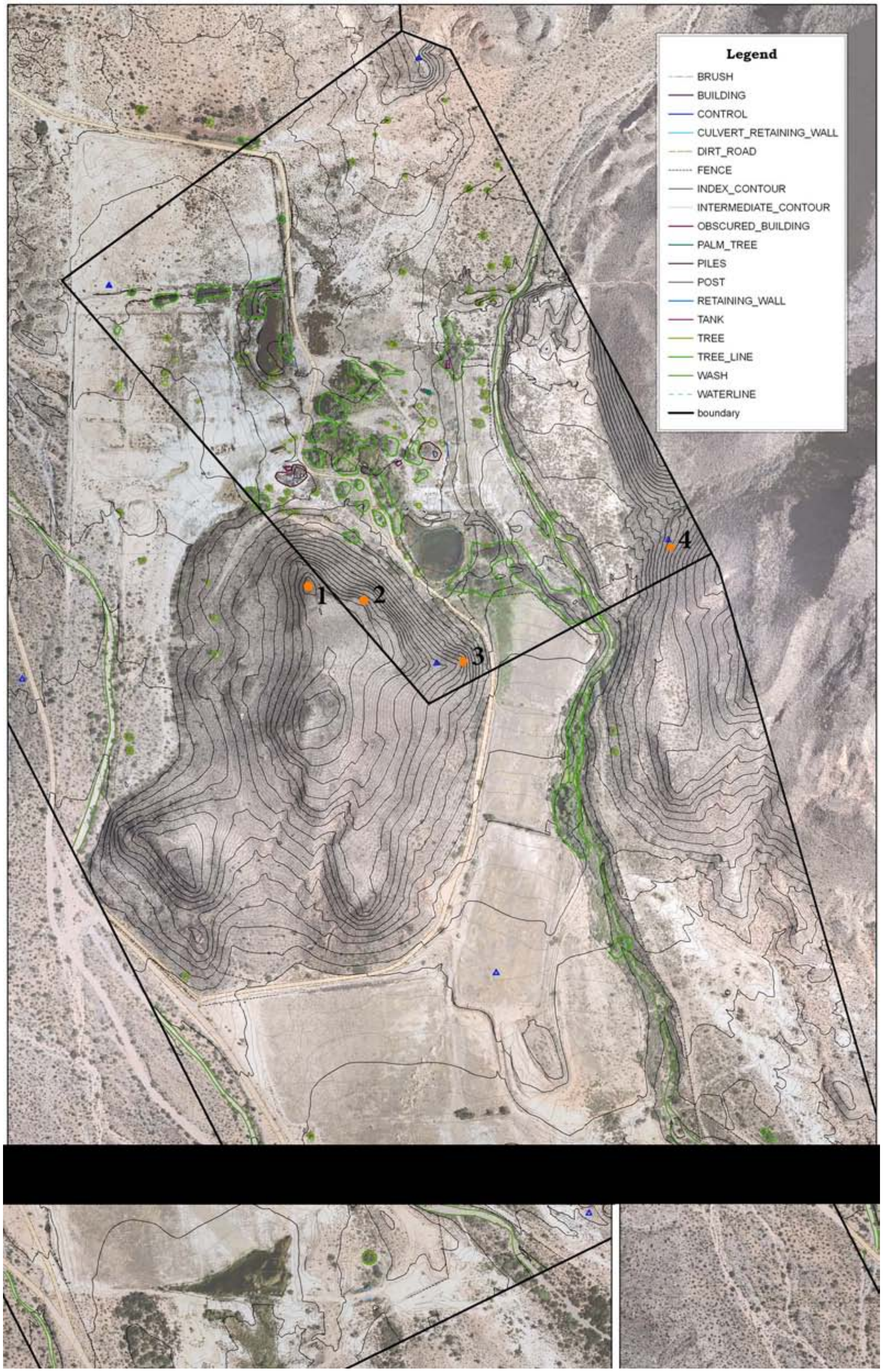

Figure 4-7 Photo location points

Photodocumentation 2006

Figure 4-8 Prior to rehabilitation initiation, panoramas (25 August 2006) from photo locations 1, 2, and 3 respectively. Pre-existing ponds in Arenas 1, 2, and 3 are obscured by dense cattail stands. Flow exiting the big pond in Arena 4 was watering a long green strip of spikerush and other wetland plant species. Green vegetation in photo 1 is at the northern end of the springs area; photo 2 is the middle; photo 3 is the southern end of springs area, Pakoon Wash, and the agricultural fields south of the springs.

Photodocumentation 2008

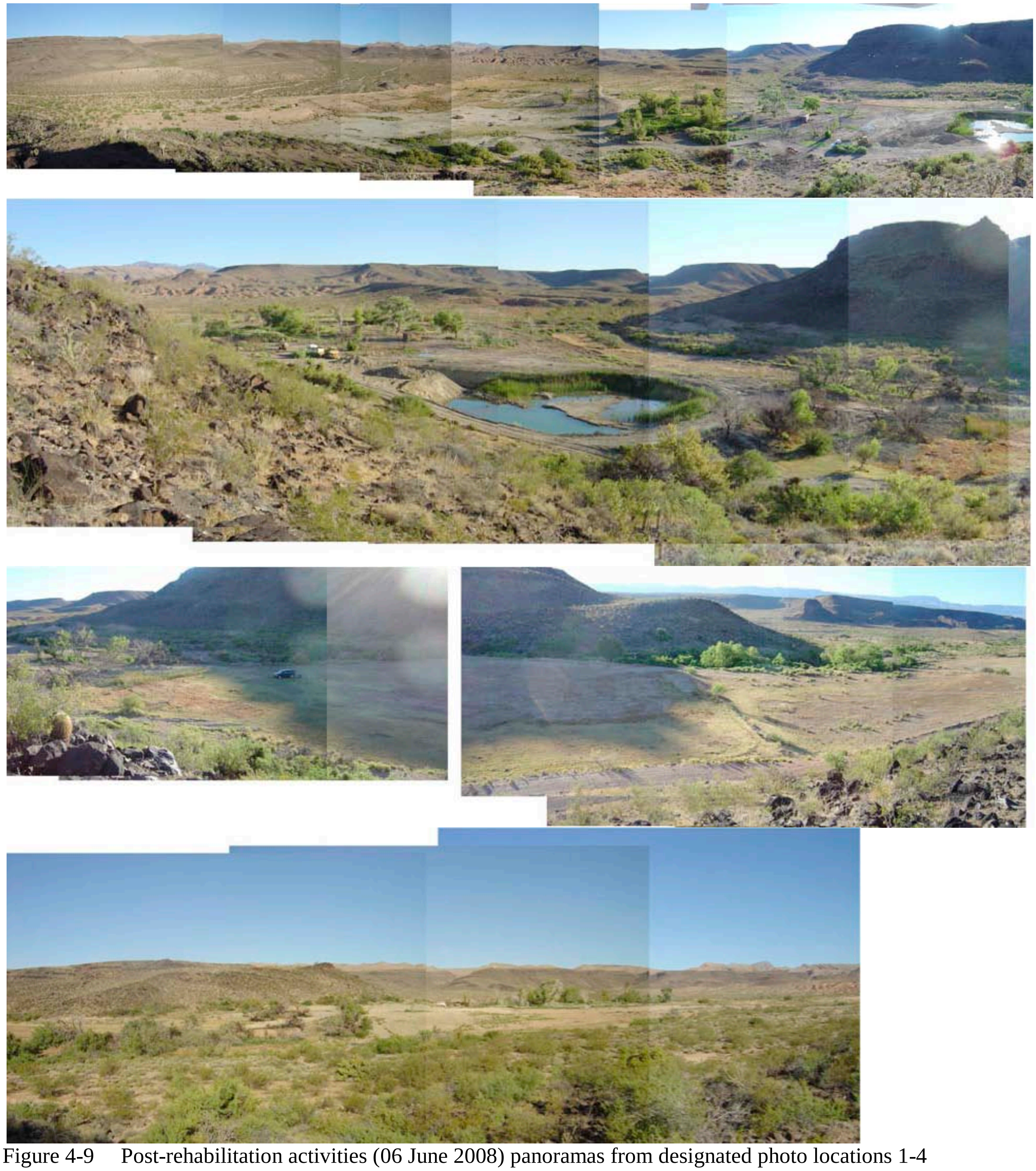

Figure 4-9 Post-rehabilitation activities (06 June 2008) panoramas from designated photo locations 1-4 respectively. Photo location 4 added after work initiated. Pond in Arena 4 is now drained through irrigation pipes to the far south end of the agricultural fields of photo 3. Note reddish strip of dried vegetation no longer supported by pond leakage, at the upper end of the agricultural fields. Recontouring most visible between the big pond in arena 4 and the cottonwood/willow trees at the north end of the springs area (arena 2). Recontouring also visible to the west of the big pond where a smaller pond was breached, providing significant additional perennial flow to the wash we refer to as Pakoon Wash, to the east of the springs area and along the east edge of the agricultural fields. Photo

location 4 is across the wash, looking to the west. In the center of the photograph, flow out of recontoured arena 3 creates a green area barely visible within the open pale green area.

Photodocumentation 2009

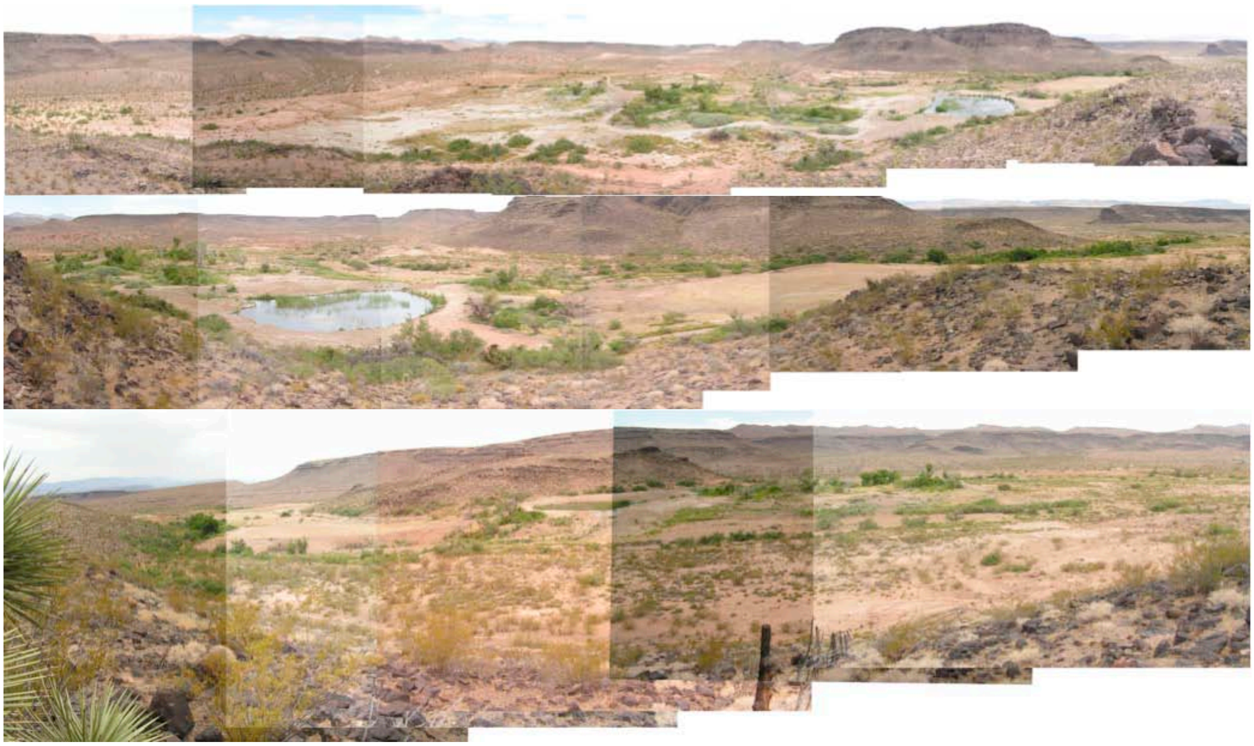

Figure 4-10 Post rehabilitation, panoramas (July 10, 2009) from photo locations 1, 2, and 4. Arena 1 has continued to wet out the hill-slope. Arenas 2 and 3 have demonstrated significant recovery of plant growth following the rehabilitation work. In arena 4, the reduced berms are visible. Additionally, the western hill-slope was restored after the agricultural road was removed and the contour was established to match the preexisting grade. The agricultural fields are shown on the right. Photo location 4, this panorama is from the new photo-location, which faces west, arena 4 is in the center of the photo and arena 1 is on the right. A thin green line of wetland plants shows where the flow from arena 3 heads toward Pakoon wash.

Photodocumentation 2010

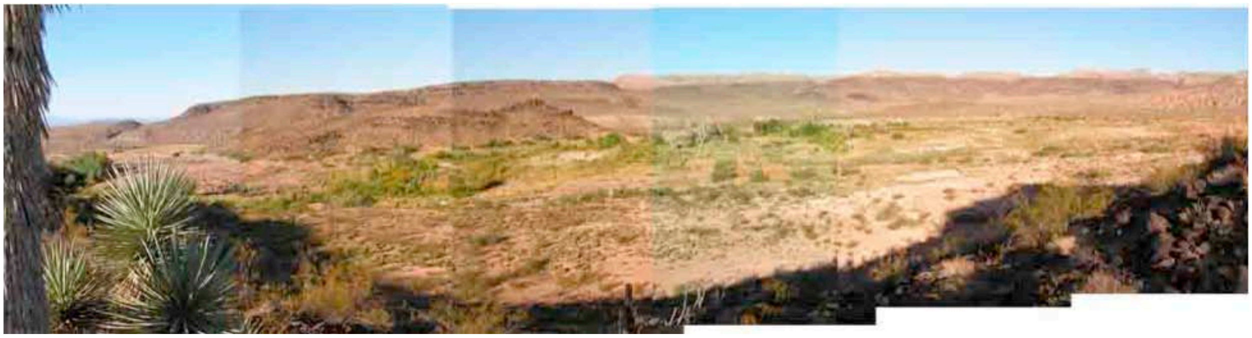
Figure 4-11 Photolocations 1, 2, and 4, 9 September 2010

4.7 Vegetation surveys (during and post-reconstruction)

Vegetation surveys were conducted throughout and after the reconstruction period. The results from the latest vegetation survey are listed below, as they are the most recent and represent the culmination of replanting and natural revegetation. For previous vegetation survey results refer to Appendix 7.4.3.

4.7.1 General observations

This last data collection site visit revealed that the Pakoon Springs project area has redeveloped substantial native vegetation, with mostly high establishment success of native phreatophytes, and much natural colonization and growth of native phreatophytes in all of the project arenas and subarenas (Arenas 1-4, 4E, 4 Channel, and Pakoon Wash). As this project does not involve irrigation, naturally wetted surfaces provide suitable habitat for phreatophytes, and therefore dryland Arena 5 is undergoing slower native plant recolonization. The total revegetated project area has increased to more than 9 ac. Avian species richness is high, with at least 18 bird species detected thus far, and high densities of Gambel's quail. In June 2009 a dozen trespass cattle were detected on the site, with much sign of feeding, trampling, and dung. Since removal of those cattle in November 2009, and removal of dung piles in early 2010, sign of their presence has greatly diminished and damaged vegetation has been replanted or is recovering. As of September 2010, there was no indication that Pakoon Creek had flooded since March 2010. While bullfrogs and mosquitofish were eliminated from Arenas 1-3 and 4E, these non-native vertebrates are still fairly abundant in the Arena 4 pond, and have been detected in low numbers in Pakoon Creek. Full removal of these species will require strategically coordinated effort, likely including cattail cutting, repeated Rotenone treatment and temporarily draining Arena 4.

4.7.2 Vegetation monitoring

Vegetation monitoring of the arenas at Pakoon Springs in September 2010 revealed low mortality, vigorous growth, and much natural recolonization on all arenas including Arena 5, which is a dryland habitat with lower recolonization (Table 4-10, Table 4-11). In 2010 a native chenopod (*Atriplex elegans*) extensively colonized peripheral, disturbed dryland habitat around Arenas 1-4, and quailbush colonized that peripheral zone as well. Growth and cover expansion of planted native Goodding's willow, *Baccharis salicifolia, Anemopsis californica*, and bulrush are vigorous, and most plantings in wetland arenas have been successful. However, successful pole planting of arrowweed (*Pluchea sericea*) in Arena 4 was limited. We recommend continued dispersal of *Prosopis glandulosa,* quailbush, and *Isocoma acredenius* seeds in Arenas 1-4, and continued monitoring of natural native recolonization in Arena 4E. The Arena 4 Channel and

Pakoon Creek have been naturally colonized by cattail, bulrush, and coyote willow (*Salix exigua*), the latter being a newly arrived native species at Pakoon Springs. Extensive colonization and rapid growth of Goodding's willow will soon result in arenas that are strongly dominated by this tree-forming willow. Shading by that species is beginning to exert strong impacts on understory species, a condition that precludes long-term persistence of many understory species. Fremont cottonwood is also extensively colonizing wetted surfaces in Arena 3; however, as it is likely that this species was introduced by prior land-owners, we have not emphasized planting it. Like Goodding's willow, cottonwood is beginning to exert shading effects in most arenas.

In addition to monitoring individual plantings, and to provide a means of assessing long-term vegetation development on each arena, we also tallied the number of species and visually estimated the percent cover of each plant species in each arena (Tables 4-11 and 4-12). For this monitoring, we divided vegetation into five strata: aquatic, ground cover (annual herbaceous taxa), shrub cover (woody perennial, 0-4 m height), middle canopy cover (woody perennial, 4-10 m height), and tall canopy cover (woody perennial, >10 m height). Each arena was inspected to detect all plant species present. Total species richness and species density/m^2 were also calculated.

This assessment revealed that a total of 37 native plant species (including the likely native *Cladophora glomerata* algal complex) were detected at Pakoon Springs in July 2009, and an additional 17 non-native plant species were found among the 6 arenas and elsewhere on the study area. The 6 arenas supported far greater species richness and percent cover of herbaceous and seedling wetland and riparian shrub and tree species than mature trees. Shrub cover has increased greatly in Arenas 2, 4, and 5, and along Pakoon Creek, while tree cover was greatest on Arenas 2, 3, and Pakoon Creek. Salix exigua naturally colonized the now-rewatered stream. This native species is likely to increase in cover and likely will attract its insect herbivore assemblage to the area. Non-native Bermuda-grass and tumbleweed made up most of the non-native ground cover in Arenas 1-4. Nonnative tamarisk has largely been removed and was no longer apparent at the site during the last survey, however maintenance is ongoing as new seedlings appear. In the very near future, the tamarisk leaf beetle will arrive in the region -- this introduced beetle reached the Bunkerville area on the Virgin River, 35 km away in late summer 2010, and will soon be widespread throughout the region.

Table 4-10 Growth and percent survivorship of native wetland and riparian plantings at the Pakoon Rehabilitation site, as measured in September 2010. Asterisks indicate natural regeneration.

Arena	Species	Ht (m) or % Cover	Year	Mean Ht (m)	N	% Mortality
1	*Anemopsis californica*	% cover	2008	[2% cover]	1	0.0
1	*Baccharis salicifolia*	Ht (m)	2008	2.1	3	0.3
1	*Populus fremontii*	Ht (m)	2009	3.5	5	0.0
1	*Prosopis pubescens*	Ht (m)	2008	2.9	7	0.0
1	*Salix gooddingii*	Ht (m)	2010	0.4	20	0.0
1	*Salix gooddingii*	Ht (m)	2009	1.9	36	0.0
2	*Anemopsis californica*	% cover	2009	[5% cover]	1	0.0
2	*Baccharis salicifolia*	Ht (m)	2010	1.3	1	0.0
2	*Populus fremontii*	Ht (m)	2008	4.3	2	0.0
2	*Prosopis glandulosa*	Ht (m)	2008	4.3	2	0.0

2	*Prosopis pubescens*	Ht (m)	2008	2.2	1	0.0
2	*Salix gooddingii*	Ht (m)	2009	4.2	6	1.0
2	*Salix gooddingii*	Ht (m)	2010	1.0	9	0.0
2	*Salix gooddingii*	Ht (m)	2008	4.0	20	0.0
3	*Anemopsis californica*	% cover	2009	[2% cover]	1	0.0
3	*Atriplex lentiformis**	Ht (m)	2009	1.0	6	0.0
3	*Eleocharis*	% cover	2009	2.0	1	0.0
3	*Populus fremontii*	Ht (m)	2009	1.5	8	0.0
3	*Populus fremontii*	Ht (m)	2010	1.3	31	0.0
3	*Prosopis pubescens*	Ht (m)	2008	4.0	1	0.0
3	*Salix gooddingii*	Ht (m)	2008	4.9	7	0.0
3	*Salix gooddingii*	Ht (m)	2009	2.4	8	0.0
3	*Salix gooddingii**	Ht (m)	2009	1.8	6	0.0
4	*Atriplex lentiformis**	Ht (m)	2009	1.9	2	0.0
4	*Atriplex lentiformis**	Ht (m)	2010	1.6	8	0.0
4	*Pluchea serica*	Ht (m)	2010	1.2	100	97.0
4	*Salix gooddingii*	Ht (m)	2008	4.8	2	0.0
4	*Salix gooddingii*	Ht (m)	2009	3.5	10	1.0
4	*Salix gooddingii*	Ht (m)	2010	0.9	100	5.0
4.5E	*Salix gooddingii*	Ht (m)	2009	3.2	3	0.0
4.5E	*Salix gooddingii*	Ht (m)	2008	3.6	15	0.0
Total	**All**	**All**	**All**	**All**	**423**	**0-97**

Table 4-11 Visually estimated cover of native (Nativity – N) and non-native (NN) plant species in each Arena: aquatic (AQ), ground cover (GC, non-woody), shrub cover (SC, 0-4 m tall woody), middle canopy cover (MC, 4-10 m perennial), and tall canopy (TC, >10 m) at Pakoon Springs, September 2010.

			Arena (% coverage)						
Species	**Stratum**	**Nativity**	**1**	**2**	**3**	**4**	**4E**	**5**	**Creek**
Anemopsis californicus	GC	N	2	5	2				3
Aster subulatus	GC	N		2					
Cynodon dactylon	GC	N	4	8	5	3	0.2		1
Datura wrightii	GC	N	0.5	0.3	1	1	1		5
Distichlis spicatus	GC	N	15	5	5	0.01	2		0.01
Eleocharis	GC	N		1	2	0.1	1		4
Helianthus	GC	N	18	25	15	10	30		5
Heliotropium	GC	N	7		1	0.2	1		0.5
Populus fremontii	GC	N			0.1				
Salix gooddingii	GC	N	0.3	1	0.1	0.01			0.01
Schenoplectus acutus	GC	N	8	2	6	3	2		
Sueda	GC	N	2	2		1	0.3		
Typha domingensis	GC	N	25	35	15	20	8		8
Veronica	GC	N		1	0.2				0.01
Chenopod weed	GC	N?	5	2	12	20	5	20	1
Bassia	GC	NN	2	1	0.1		1		
Brassica?	GC	NN		5	0.3	1	2		1
Bromus rubens	GC	NN	0.2					0.1	
Melilotus	GC	NN		1	0.1		3		0.1
Polypogon monspeliensis	GC	NN	3	0.1	0.2	0.3	0.1		0.3

Salsola iberica	GC	NN	3	0.1	0.2	1	1		
Solanum angustifolium	GC	NN		0.1	0.1		1		0.01
Populus fremontii	MC	N	1	6	3				
Prosopis glandulosa	MC	N	3	2	3		1		1
Prosopis pubescens	MC	N		0.01	3				1
Salix gooddingii	MC	N	3	18	10	3	12		15
Acacia greggii	SC	N				1		15	6
Atriplex canescens	SC	N	1						
Atriplex lentiformis	SC	N		1	12	1	0.1		
Baccharis salicifolia	SC	N	0.5			0.1			6
Baccharis sergiloides	SC	N	0.1						
Isocoma acredenius	SC	N	1	3	5	0.1	2	20	1
Larrea tridentate	SC	N						1	
Phorodendron californicum	SC	N						2	0.01
Pluchea sericea	SC	N			3	0.1	6		20
Populus fremontii	SC	N	5	6	3				
Prosopis glandulosa	SC	N	3	2	3	0.01	2	12	2
Prosopis pubescens	SC	N	2	2	4	0.01	2		2
Salix exigua	SC	N			0.2				1
Salix gooddingii	SC	N	4	20	12	5	15		20
Vitis arizonicus	SC	N							3
Populus fremontii	TC	N		5	2				
Salix gooddingii	TC	N		15	10		18		8

Table 4-12 Summary of visually estimated cover of native (Nativity – N) and non-native (NN) plant species richness in each Arena: aquatic (AQ), ground cover (GC, non-woody), shrub cover (SC, 0-4 m tall woody), middle canopy cover (MC, 4-10 m perennial), and tall canopy (TC, >10 m) at Pakoon Springs, September 2010.

Species	**Stratum**	**Nativity**	**Arena (% coverage)**						
			1	**2**	**3**	**4**	**4E**	**5**	**Creek**
Subtotal Percent Cover	GC	N	86.8	89.3	64.4	58.3	50.5	20.0	27.5
	SC	N	16.6	34.0	42.2	7.3	27.1	50.0	61.0
	MC	N	7.0	26.0	19.0	3.0	13.0	0.0	17.0
	TC	N	0.0	20.0	12.0	0.0	18.0	0.0	8.0
	GC	NN	8.2	7.3	1.0	2.3	8.1	0.1	1.4
	SC	NN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	MC	NN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TC	NN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Cover, N & NN	GC	N&NN	95.0	96.6	65.4	60.6	58.6	20.1	28.9
	SC	N&NN	16.6	34.0	42.2	7.3	27.1	50.0	61.0
	MC	N&NN	7.0	26.0	19.0	3.0	13.0	0.0	17.0
	TC	N&NN	0.0	20.0	12.0	0.0	18.0	0.0	8.0
No. Native Species by Stratum	GC	N	11	13	13	11	10	1	11
	SC	N	4	6	6	3	6	1	4
	MC	N	3	4	4	1	2	0	3
	TC	N	0	2	2	0	1	0	1
No. Nonnative Species by	GC	NN	4	6	6	3	6	1	4

Stratum	SC	NN	0	0	0	0	0	0	0
	MC	NN	0	0	0	0	0	0	0
	TC	NN	0	0	0	0	0	0	0
Total No. Species, N & NN	GC	N&NN	15	19	19	14	16	2	15
	SC	N&NN	4	6	6	3	6	1	4
	MC	N&NN	3	4	4	1	2	0	3
	TC	N&NN	0	2	2	0	1	0	1

4.8 Rehabilitation activities

The section documents the rehabilitation activities, including general construction, revegetation, and arena specific activities. The discussions about rehabilitation arenas follow the numbering in Fig. 4-12 (see also Table 4-13).

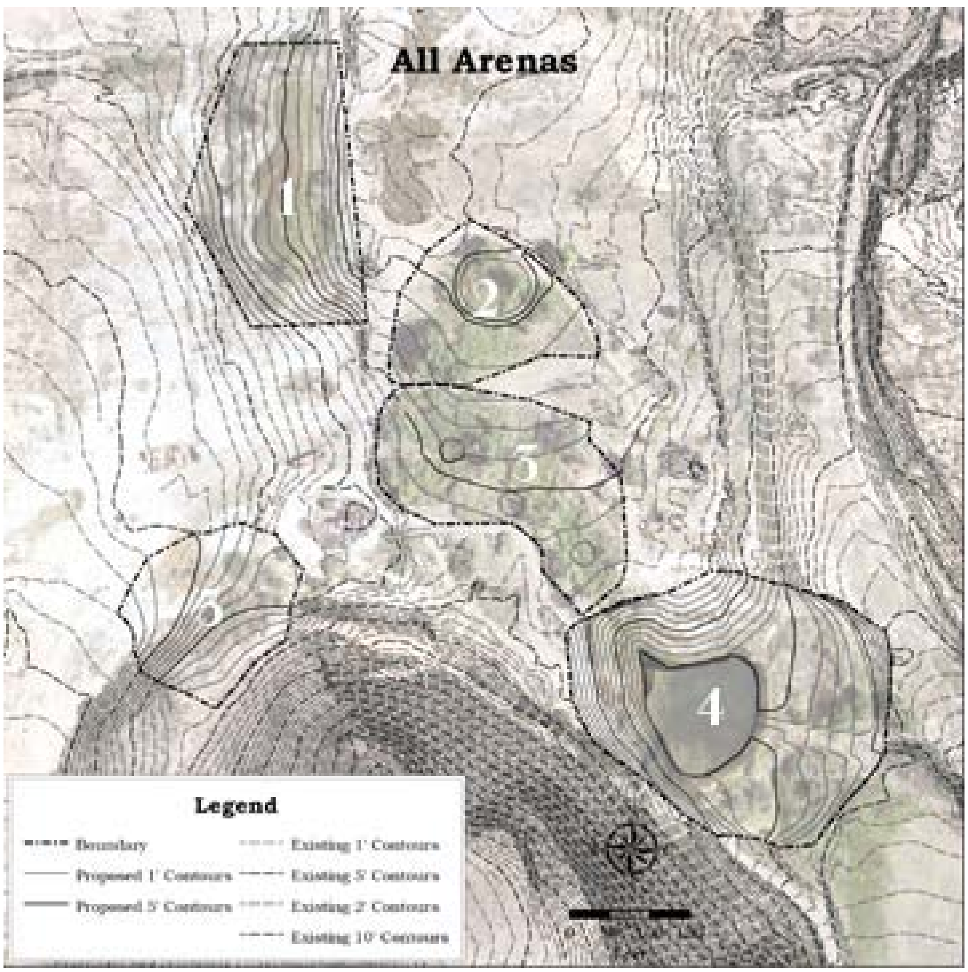

Figure 4-12 Existing and target contours for the five arenas, see Table 4-13

4.8.1 Construction

Construction activities were initiated in the spring of 2008 and continued in spring 2009 and 2010. By early June each year, the onset of summertime heat precluded further work.
Prior to construction activities, and based on our site assessment, the entire Pakoon Springs site was re-fenced to exclude feral burros and cattle (Fig. 4-13). The fence encompasses all five

Arenas, the agricultural fields, and approximately one mile of Pakoon Wash. A new gate and cattle guard were installed at the north end of the project. An existing gate remained at the south end of the project. Wash away gates were installed where the fence crossed Pakoon Wash. The lower strand of the fence is not barbed wire, to allow wildlife to crawl under it unharmed.

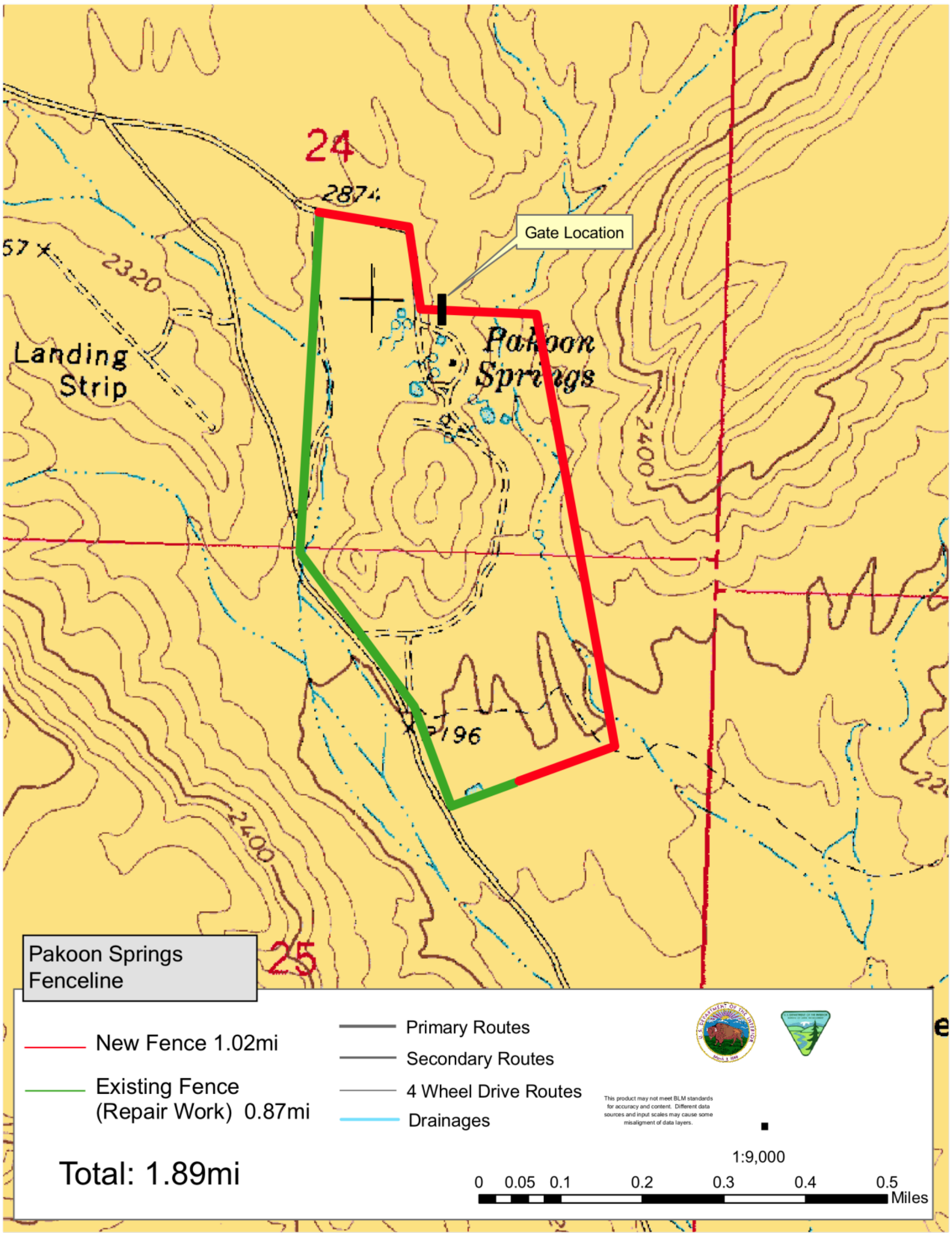

Fig. 4-13 Map showing new fence surrounding Pakoon Springs.

Earth work
A track hoe excavator, bulldozer, and dump trucks were used to move soil, fill the ponds, and recontour the springs topography, and to restore flow and a natural appearance to the springs system. Berms were removed in Arenas 1, 2. 4E, and the south end of Arena 3. The berm around the largest pond (Arena 4) was lowered and reshaped. In March 2009, the upper section of Arena 3 was filled in. It had been left uncovered during the original earth work to supply native planting material for other arenas.

Bare recontoured areas were ripped on the contour to reduce potential erosion, following the construction process. The irrigation outflow pipe in Arena 4 was retained to aid in the management of the water level and removal of exotic species, including bullfrogs and mosquito fish. The outflow pipe valve can be completely closed. The pipe drains from Arena 4's south-east edge. The valve and pipe outlet were enclosed in a masonry structure in February 2009 that has metal grates covering access holes. The structure may be removed in the future if control of the water level is no longer desired.

In February 2009, we drained the pond in Arena 4 and lowered the berms surrounding this pond by 5 to 10 feet. Soil from the berms was 1) pushed into the pond to reduce the size of the open water, 2) used to recontour the western edge of the pond, 3) used to obliterate an undesired road, and 4) hauled onto the agricultural fields for future contouring. Following the berm reduction, the edges of the pond and an area on the west side were dug out with the track hoe to maintain some open water surface free of cattails (they do not grow well in deeper water). The relatively fine-grained sediment from the pond bottom, distributed on the west side of Arena 4, is facilitating natural revegetation from local wind-borne seed.

In March 2009, a channel leading east from Arena 4 into Pakoon Wash was created using a track hoe excavator. Pond liner material was laid down with overlapping edges to stabilize the ground and reduce water penetration into the hillslope. A layer of locally-obtained rock, cobble and dirt was spread onto the liner. This outflow construction preserves the open water of Arena 4, while returning flow east into Pakoon Wash. Outflow from Arenas 3 and 4E joins the flow from Arena 4 and then enters Pakoon Wash, downslope to the east.

Table 4-13 Dimensions and recontouring data of arenas 1-5, Pakoon Springs Rehabilitation Site, Arizona Strip, as of June 2008.

Arena	Perimeter (ft)	Area (ft^2)	Cut (yd^3)	Fill (yd^3)	Net Volume (yd^3)	Approx. Project Area (ac)	Approx. Recontour Hrs
1	1003.5	61011.4	3045.3	808.2	-2237.1	1.0	96
2	756.7	35870.8	1178.8	31.2	-1147.6	1.0	190
3	1009.9	54145.8	1154.7	108.4	-1046.3	1.5	180*
4	1198.8	102900.1	17599.1	1081.7	-16517.4	2.0	250
5	709.9	35154.0	66.6	2246.9	2180.3	0.5	0
Total	**4678.7**	**289082.0**	**23044.5**	**4276.4**	**-18768.1**	**6.0**	**716**

4.8.2 Non-native species removal

Existing non-native tamarisk trees, fewer than 100 trees, were treated in 2006 by cutting and treating woody stumps with herbicide, through a separate BLM-National Park Service effort. Seedlings and tamarisk discovered during rehabilitation were hand pulled or mechanically removed, as were other non-native trees. Mosquito fish and bullfrogs were eliminated in Arenas 1, 2, 3, and 4 East (a smaller spring source on the east flank of the big pond. The ponds were filled with the material from the berms and the habitat no longer exists for those species. The elimination of those species is proving to be more difficult in Arena 4, as the cattails have grown back and greatly improved the hiding cover for both mosquito fish and bullfrogs. We cut the cattails and hunted bullfrogs on two separate occasions. However, we were not able to capture all of them, and they have reproduced. To eradicate the mosquito fish we applied Rotenone to the pond and outlet channel. Although many mosquito fish were killed, we were unsuccessful in killing all of them. The efforts to eradicate these species are on going through a removal plan coordinated with the Arizona Game and Fish Department and the US Fish and Wildlife Service

4.8.3 Revegetation

In 2008, at the start of rehabilitation, the small wetland areas around the springs were strongly dominated by cattails. Native riparian vegetation in these areas was either no longer present, or had been reduced to a few plants and degraded by historic and recent livestock grazing. Native riparian vegetation species remaining in small numbers included honey and screwbean mesquite, Goodding's willow (*Salix goodingii*), Fremont's cottonwood (*Populus fremontii*; likely introduced to the site), and desert broom (*Baccharis* sp.).

In 2008, revegetation was initiated on the upper Arenas 1-3. The seep and spring complexes were revegetated with native, indigenous species to provide a plant community structure composed of a grass and forb understory with a multi-level canopy of Goodding's willow and desert broom. Local seed was collected to ensure genetic integrity and to increase the likelihood of revegetation success with minimal to no irrigation. Fremont's cottonwood occurs at the site, and while that species may occur naturally, some of the existing trees likely were planted by the previous landowners, as was the case at springs elsewhere in the area (e.g., Tassi Springs). It is advantageous to maintain Fremont cottonwood from a habitat diversity standpoint, as many woodpecker, neotropical migrant, and raptorial bird species use tall-canopy cottonwood. Up to 47 turkey vultures used one of the large cottonwood trees to roost during March 2009 construction activities. We pole planted Fremont cottonwoods in low density at Pakoon Springs. Propagules of the preferred species were collected during the construction process from cuttings, and were planted in moist soils in Arenas 1-3 adjacent to spring sources and along waterways created during rehabilitation. Initial establishment and growth was very successful. Regeneration of ground cover and Goodding's willow trees will enhance habitat value of the site to migrating and summer resident birds and other wildlife. Already, abundant Goodding's willow and cottonwood seedlings have established in wet areas around each arena.

The western hillslope of Arena 4 was planted with locally harvested native seeds (Table 4-14) gathered in 2008 and spread in April 2009 by a volunteer group of Kaibab Paiute and GCWC volunteers and staff. In 2008-2010, yerba mansa and bulrush was transplanted from Arena 3 into Arenas 2-east, 3-east, 4-east. Spikerush was initially transplanted from below Arena 4 where the irrigation outflow had previously leaked, to Arenas 1-3. Later, spikerush was observed colonizing wet areas unaided. Additionally, Gooding's willow and cottonwood clipping were pole planted in newly wetted soils around Arenas 1 – 4. Around the Arena 4 pond, pole plantings focused on the south, north and east banks, to stabilize the hillslope and distribute trees away from the pond's edge.

Table 4-14 Seeds spread with collection locations

Plant		Collection Date	Collection location
Pluchea	Arrow weed	6/08	Pakoon
Larrea	Creosote	5/08	Pakoon, second batch with no location information
Penstemon palmeri	Penstemon	6/08	Whitney pocket
Salvia	Purple sage	5/08	Gold Butte Rd
Ambrosia	Ragweed	5/08	Gold Butte Rd
Psorothamnus	Indigo bush	5/08	Gold Butte Rd
Krameria	Range ratany	5/08	Gold Butte Rd
Yucca	Yucca	5/08	Gold Butte Rd
Isocoma	Jimmyweed	12/08	Gold Butte Rd
Atriplex	Four-wing saltbush	12/08	Gold Butte Rd
Nicotiana	Desert tobacco	5/08	Pakoon
Sphaeralcea	Globe mallow	unrecorded	Unrecorded, local
Gutierrezia	Snakeweed	unrecorded	Unrecorded, local
Encelia	Brittlebush	5/08	Gold Butte Rd

4.8.4 Irrigation

Due to the remoteness of the site, the installation of an irrigation system requiring electric or gas-powered pumps was not feasible. The installation of pumps requires frequent visits by maintenance personnel to guarantee regular operation of an irrigation system. Therefore, the installation of plant materials was limited to areas where sufficient soil moisture was available to support the plantings. Reseeding and native plant colonization of dry upland areas was aided by timely winter and spring rains in 2009/2010.

4.8.5 Arena 1 – site specific information

Pre-existing conditions

Arena 1 was an excavated quasi-rectangular pond, steeply bermed, and holding only shallow water (Figs. 4-12 and 4-14, Table 4-13). It was almost completely covered by cattail, with 1-2 Goodding's willow at the north and south ends, and with scattered honey mesquite, catclaw, and *Isocoma* along the bases and tops of the berms. The pond was thoroughly infested with nonnative bullfrogs and mosquitofish. Although we had not detected flow, it was presumed that Arena 1 represented a place at which a springs source in the paleosprings surface upslope had been excavated by the previous landowners, and that the 10' tall berm there had been constructed to retain the flow, presumably for the pastures downslope or other purposes. The full area under rehabilitation in Arena 1 was approximately 1.0 ac.

Rehabilitation methods and progress

The primary objective for this arena was to eliminate the cattail, bullfrog, and mosquitofish pond habitat, burying it with up to 8 ft of fill. This was accomplished by pushing the berm into the pond using a trackhoe and redistributing fill with a dumptruck and bulldozer. Arena 1 has been reworked into a gently undulating, smoothly contoured surface, accommodating the two springs outflows that were discovered there (Figure 4-15). We preserved existing Goodding's willow, and some of the mesquite, and catclaw shrubby trees.

Existing habitat for nonnative frogs and fish was eliminated. Initial plantings established a wet cienega developing from the base of the desert paleosprings terrace, with flows directed south and west from two sources. Surrounding habitats are dry meadow and dry riparian shrubland. Flow is directed to maximize the site's wetland and riparian habitat potential. Throughout 2009, Arena 1 springs continued to spread and wet areas of the adjacent hillslope. As new wet areas were observed, willow poles were planted in the moist soil to provide riparian habitat. Previously planted bulrush, spikerush, yerba-mansa, spread out and many willow and cottonwoods seeded naturally.

Revegetation

In the two springs sources detected within Arena 1 (Fig. 4-16), some of the moist soil surface was initially revegetated with native wetland vegetation derived from local stock. The following species were planted: bulrush (*Schenoplectus*), spikerush (*Eleocharis*), and yerba-mansa (*Anemopsis*), along with Goodding's willow (*Salix gooddingii*) in areas with wet or saturated soil, and riparian seepwillows (*Baccharis*). Plantings and reseeding included honey mesquite (*Prosopis glandulosa*) and quailbush (*Atriplex lentiformis*) in riparian areas, and paleosprings jimmyweed (*Isocoma*), inkweed (*Sarcobatus*), and related vegetation in the drier periphery. In the spring of 2010, approximately 50 additional Goodding willow poles were planted in the wet soil. Wetland plugs (up to 2 feet in diameter) were removed from other arenas or the stream habitat area and established at 1-2' intervals. Five or six *Baccharis* plants were successfully rescued from the future outflow area of the Arena 4 pond and transplanted to Arena 1 using the trackhoe and skidsteer. A similar attempt was made with a large quailbush but the root structure was too large to fully dig up even with the excavator, and the transplant failed. Fifteen to twenty poles of *Salix gooddingii* were pole planted to generate a transition from wetland to dryland riparian vegetation, in a design consonant with the available habitat. Peripheral, drier habitat was planted with saltgrass (*Distichlis spicata)* rootstock, and opuntia cactus pads and seeded with *Isocoma, Sarcobatus, and Atriplex lentiformis*. Saltgrass is spreading across and covering much of the top of the newly created spring mound surface.

Figure 4-14 Arena 1 prior to initiation of rehabilitation (26 August 2006). Note berm and cattail-filled pond.

Figure 4-15 Arena 1 rehabilitation progress (06 June 2008). Berms removed, pond filled and recontoured, cattail stand buried. Goodding's willow trees preserved on perimeter of former pond. Small photo (15 July 2008) shows native wetland and riparian vegetation at two spring sources (wetted areas) that emerged after recontouring. Center of large image is the photo location for the small image.

Figure 4-16 The transplanted riparian vegetation in Arena 1 springs (July 2009) is thriving and non-transplanted native vegetation has sprouted. The springs have developed into two main groups: on the right side of the image the ground has wetted out, flowing in a southern direction toward the bottom of the image, and in the center of the image the springs have spread across the hillslope in a western direction (toward the left side of image).

4.8.6 Arena 2 – site specific information

Pre-existing conditions

Arena 2 was a deeply excavated circular pond, less steeply bermed than the Arena 1 pond, and holding water as much as 5' in depth (Figs. 4-12 and 4-17 to 19, Table 4-13). It was virtually completely covered by cattail, with peripheral Bermuda grass, *Anemopsis*, and saplings of Goodding's willow on the berm. A 6'-tall, 3'-diameter culvert had been inverted and sunk as a well to a depth of 14' on the east side of the pond, and a large Goodding's willow had grown up densely around it. The well brought water up and the water flowed out into the surrounding area to the east. A large Fremont cottonwood and other smaller trees exist at the site, particularly on the east side. *Isocoma* and *Sarcobatus* occurred in the periphery around the arena. The pond was densely infested with nonnative bullfrogs and mosquitofish. Like Arena 1, Arena 2 likely represented a place at which one or more springs emerged. The site had been excavated by the previous landowners, and the berm had been constructed to retain the flow, presumably for an orchard downslope, for domestic use in the dwellings, and/or for other purposes.

Rehabilitation methods and progress

The berm around Arena 2 was breached on the east side. Then the pond was filled with soil excavated locally. Arena 2 is becoming a smoothly contoured wet cienega surface, and all existing habitat for nonnative frogs and fish was eliminated. Arena 2 is now the highest in elevation and flows in all four cardinal directions from this spring mound. The site is being managed to maximize its wetland and riparian habitat potential, emphasizing bulrush and

Anemopsis wetlands, seepwillow and Goodding's willow cover, and with peripheral riparian honey mesquite and quailbush, and paleosprings riparian *Isocoma*, *Sarcobatus*, along with related vegetation around the dryland periphery.

Because of the relatively large amount of flow anticipated from Arena 2, we prioritized rehabilitation efforts there, and in 2008 performed the rehabilitation activities listed below.

Step 1. Fill in the pond. The first step was to breach the berm on the west side of the pond, then fill it completely with at least 6' of soil. We estimated that the pond was about 5' in depth, but the infilling by cattails reduced the depth somewhat. The berm was pushed from west to east to direct flow into a small constructed channel, and soil needed to complete the infilling of the pond was mined from the fill slope where the previous owner's house was located.

Step 2. Remove the culvert well. The culvert well was pulled out using the track hoe excavator to grasp the culvert and extract it and then replace soil within the mound of an existing large willow. Preservation of the Goodding's willow tree at the culvert well was achieved, as were other established trees, where practicable.

Step 3. Recontour Arena 2. The site was recontoured into a spring mound configuration.

Additional Construction Notes. Equipment operators were instructed to limit damage to the large, mature Goodding's willow trees that occured in a stand about 20 yards to the southwest of Arena 2. Also, we avoided operating equipment over the yerba-mansa (*Anemopsis*) stand in that area and at the north end of Arena 3. The native vegetation in Arena 2 was flagged off, and some of the existing native plants that lay in the construction path there were transplanted immediately to revegetate other areas of Arenas 1-3. Arena 3 construction activities were completed in 2008. In 2010, a pipe was installed in the service road that is east of Arena 2, as flow from the spring mound had breeched an existing road circling the north end of the Pakoon Springs site.

Revegetation

Relatively abundant flow for the rehabilitation area emerges to create several hundred square feet of saturated soil in Arena 2. This flow is creating a substantial wet meadow habitat from this area down onto the terraces of Pakoon Wash to the east. Some flow eventually may reach Pakoon Wash, and begin to transform the immediately adjacent and presently ephemeral reach into a much longer perennial stream. Moist soil surfaces were vegetated with native wetland vegetation derived from local stock, including *Eleocharis, Schoenoplectus*, and *Anemopsis*. Wetland plugs were removed from other arenas and established at 1-2' intervals, depending on the area to be revegetated. We planted 50 or more ½" - 2" poles of *Baccharis*, *Salix gooddingii*, and 50 *Distichlis* root masses to generate a transition from wetland to dryland riparian vegetation, in a design consonant with the available habitat.

During 2009, Arena 2 developed small channels to the west and to the north. The western channel flows towards Arena 1, but not yet crossing into it. The northern channel curves eastward and joins the east-flowing channel. Native wetland vegetation initially planted had matured by 2009. Dense stands of Gooding's willow recruited on the southern side of Arena 2 and were harvested to plant other arenas. In 2010, we continued to pole plant Goodding's willow in the newly wetted soils and to stabilize the east-flowing channel. Additionally, yerba mansa was transplanted to the western, northern and eastern newly wetted soils. Saltgrass has expanded from the south to the west side of the of the spring mound, and now covers a considerable area.

Figure 4-17 Arena 2 prior to rehabilitation activities (25 August 2006). View toward northeast of berm around cattail pond. Thin band of smaller willows and cottonwood around periphery. Tall willow and cottonwood are on north side. Inset overview shows same 2 large trees on north side with cattail stand in center. Willows on right side of inset were growing on top of culvert with spring source emerging through the mound it formed.

Figure 4-18 Arena 2 rehabilitation progress after removal of berm and infilling of pond (15 July 2008) showing recontoured slightly mounded area with spring emerging near Goodding's willow. Much of the flow

was to the east from the tall Goodding's willow. Inset shows colonization by native datura, rushes and sunflowers around flow on north side, east of the tall willow. With removal of buried piping some trees were expected to readjust their architecture in response to changing soil moisture conditions.

Figure 4-19 Arena 2 after rehabilitation in July 2009, springs spread out and flowed from Arena 2 in northern, western, and eastern directions although reestablished vegetation in the photo obscures the view of these small channels. The wetland vegetation recovered from rehabilitation work and spread as the springs wetted new soil.

4.8.7 Arena 3 – site specific information

Pre-existing conditions

Arena 3 was a trenched, heavily-altered desert wetlands that sloped gently to the south, and produced flow that entered Arenas 4 and 5 through eroding channels. (Figs. 4-12 and 4-20 to 22, Table 4-13). In recent years, Arena 3 had two or more open water ponds, and a highly modified stream channel that passed its flow into Arena 4. The depth of Arena 3 ponds may have exceeded 3'; however, those ponds had become densely invaded by cattail and were no longer serving as open water habitats. Substantial stands of native *Anemopsis* and *Schoenoplectus* sedge occur on the northern end of Arena 3, with peripheral Goodding's willow, quailbush, *Isocoma*, (likely) non-locally derived Fremont cottonwood, and fully nonnative Bermuda grass around the drier periphery. The largest Goodding's willow trees at the north end likely predate Anglo-European settlement of Pakoon Springs, and were protected during site recontouring. The wetlands were densely infested with nonnative bullfrogs and mosquitofish. Several spring sources emerged in this arena. The channel and perhaps the ponds themselves were excavated by previous landowners, and former flow to the east or west may have been manipulated to augment flow into the Arena 4 pond.

Rehabilitation methods and progress

Arena 3 has become a wet cienega around flows from at least two springs sources directed to the east into Pakoon Wash. Arena 3 is being managed towards bulrush, spikerush, and *Anemopsis* wetlands. The site was expanded to include:1) riparian habitat dominated by seepwillow and Goodding's willow cover; and 2) peripheral dry riparian habitats dominated by arrow weed, honey mesquite and quailbush. Suitable habitat for bullfrogs and mosquito fish no longer exists.

At least 6-8' of peat underlies the core of Arena 3, and a relatively large amount of flow arises from it, creating unstable footings for large equipment. Arena 3 provided the main source stock for revegetating other arenas. Also, flow from Arenas 3 now also contributes to making Pakoon Wash a perennial stream, enhancing riparian rehabilitation potential along that channel. As a consequence of complex interactions between rehabilitation elements and resource conditions, prioritization of rehabilitation steps was necessary to accomplish the rehabilitation objectives, and the following rehabilitation activities were conducted.

Step 1. Burn off the winter-dead cattails. This action exposed the former pool areas and revealed where safe footing existed for the large equipment needed to fill in and recontour the site. This was accomplished early in our rehabilitation process at Arena 3 to improve site evaluation.

Step 2. Develop east-flowing channel. A 3' wide, 1' deep channel was constructed directing flow eastward from Arena 3 towards Pakoon Wash, based on the site evaluation and decisions made during rehabilitation planning. The eastward Arena 3 diversion channel starts at the southeast side of Arena 3and joins the outflow from Arena 4 lower down the east slope toward on the flood plain of Pakoon Wash. The larger, deeper southward-directed Arena 3 channel was filled and the flow to Arena 4 was interrupted. During the attempt to fill in the this channel at the northwest end of the Arena 4 pond, significant emerging springflow was observed(apparently greater discharge than any of the other post-construction sources) and removed the fill material rapidly. The decision was made to leave this newly recognized source uncovered and the channel at the upper end of Arena 4 was then lined with stratified coarse rock and gravel to create a diverse bottom substrate for invertebrates.

Step 3. Recontour the interior Arena 3 channel. We filled and recontoured the Arena 3 stream allowing it to gently meander through the northern half of the arena. The gradient is sufficiently low in the upper (north) one third of Arena 3 that this channel is shallow (less than 2 inches deep at maximum depth) and carries the flow into the newly created channel running east, out of the south end of the arena.

Additional Construction Notes. Equipment operators were requested to limit damage to native wetland vegetation (except cattails), particularly to large, mature Goodding's willow trees that are dispersed throughout Arena 3. Also, they avoided running equipment over the yerba-mansa (*Anemopsis*) at the north end of Arena 3 and did not complete infilling of the uppermost ponds until after salvage of much bulrush and yerba mansa from those areas for use in revegetation of other areas of Arenas 1-3.

Filling in the ponds of arena 3 have eliminated standing water greater than ~1 foot of depth, thereby eliminating bullfrog and mosquitofish habitat. No observations of bullfrogs or mosquitofish have been made in arena 3 since the standing, deeper water was eliminated.

Revegetation

In 2008, the abundant flow emerging to create surface water in Arena 3 was used to develop a substantial wet cienega habitat on the terraces of Pakoon Wash to the east. We used rock to construct small check dams, which prevented gully erosion in the fine textured soil. The flow from Arena 3 was sufficient to reach Pakoon Wash. We planted native wetland vegetation on some of the moist soil surfaces using *Eleocharis*, *Schoenoplectus*, and *Anemopsis*. Wetland plugs were removed from other arenas or the stream habitat area and established at 1-2' intervals, depending on the area to be revegetated. *Distichlis* rhizomes were planted in appropriate microsites (i.e., on moist, low gradient soils), and *Baccharis* and *Salix gooddingii* were pole planted to generate a transition from wetland to dryland riparian vegetation, in a design consonant with the available habitat. Peripheral and drier habitats underwent rapid, natural, and extensive colonized by native shrubs. We augmented this natural colonization with seeds and transplanted saplings of *Isocoma, Sarcobatus, and Atriplex lentiformis* added in early-mid springs months.

Native wetland vegetation was planted on some of the moist soil surfaces using spikerush, bulrush, and yerba-mansa. The latter species has spread north and joins with other patches associated with Arena 2. Seepwillow and Gooding's willow pole plantings are thriving and have begun to generate a transition from wetland to dryland riparian vegetation. In addition, cottonwoods saplings have spread naturally throughout the eastern flow of Arena 3.

In 2010, we pole planted Goodding's Willow into the eastern flow going down the upper terrace and along the flow heading toward Pakoon Wash. Additionally, we transplanted yerba-mansa into the eastern flow, taking advantage of the wetted soils. On the western edge of Arena 3, we pole planted willows.

Figure 4-20 Arena 3 (middle section; see Fig. 4a panorama) prior to rehabilitation activities (25 August 2006). Long narrow, relatively deeply excavated channels filled with cattail, with some Goodding's willow and quailbush on outer edge of channel. Note wooden shed for reference.

Figure 4-21 Arena 3 rehabilitation progress (06 June 2008). Wooden shed is on upper left side of photo. Springs are emerging from the now-infilled channel and flowing to east across gentle recontoured slope. Pakoon Wash is visible along upper edge of photo. Willow in upper center of photo was dewatered after irrigation piping removal. Spring flow directed toward the willow is restoring water to that tree. Arena 4 pond is to the right beyond this photo. Small image (15 July 2008) shows revegetated wetlands in spring-flow between wooden shed and the Goodding’s willow tree, with bulrush and spikerush.

Figure 4-22 Arena 3, July 2009, riparian vegetation has recovered and the springs have spread out flow in an easterly direction, towards Pakoon wash. The northern section of the springs has spread northward and is close to joining the wetted soils of Arena 2. The shed was destroyed in a fire in 2008.

4.8.8 Arena 4 – site specific information

Pre-existing conditions

Arena 4 was a heavily modified desert springs pool complex, enclosed within a tall (ca 12') berm-on-berm, which formed a 10'-deep pond (Figs. 4-23, 24, and 4-25 to 27, Table 4-13). The Arena 4 pool received inflow from newly discovered springs in lower Arena 3 (now upper Arena 4 channel) and through the eroding Arena 3 channel to the north. Springs and springs gasses bubbled up through the clear water in the pond, particularly in the middle and on the north and east sides. Discharge from the pond had been directed southward through a drain and valve system from the deepest part (southern side) of the pond, discharging water into a lengthy underground agricultural piping network to fields south of the springs. Rare overflow from the Arena 4 pond was sent via a weir system towards the southeast, down a steep slope towards Pakoon Wash. The pond was densely infested with nonnative bullfrogs and mosquitofish; however, the Arena 4 pond also was used by migrating waterfowl, and had delightful, clear, warm water. The edge of the pond was surrounded by a dense stand of cattails.

Riparian vegetation was present around the overflow waterworks, particularly south and southeast of the pond. On the east periphery of Arena 4 lay another, smaller pool covered by cattails and surrounded by a dense stand of arrowweed (*Pluchea sericea*). A dense woodland of honey mesquite, seepwillow, Goodding's willow, and other riparian phreatophytes occurred downslope and along the southeast overflow path. These riparian stands likely were supported by leakage from the Arena 4 pool, but the smaller pool was supported by another significant spring east and downslope from the main pool. Wetlands had developed in the leakage from Arena 4 in the northernmost agricultural field, supporting spikerushes and saltgrass (*Distichlis spicata*). Peripheral drier riparian habitats around the Arena 4 pool supported honey and screwbean mesquites, quailbush, *Isocoma*, and nonnative Bermuda grass.

Warm, limnocrene (pool-forming) springs are among the richest sites for endemic biodiversity and rare biota in the Southwest; however, no evidence of hydrobiid or other endemizing

Mollusca had been detected there, nor had any other rare or unique biota been found in or around the Arena 4 pond. In December 2007, Dr. Don Sada inventoried each of the four wet Arenas for the presence of mollusks. None were found. During construction, we searched in vain for evidence of shells and other paleontological materials to determine whether rare taxa previously occupied the pool complex, or whether the soils there indicated that this pond has been a long-term feature of the Pakoon Springs complex. In the absence of such evidence, we conclude that the large pond likely had been largely constructed by land-owners over the past century, but the geomorphology of the site suggests that a smaller pool might have been present.

Rehabilitation methods and progress

Arena 4 has been reshaped to: 1) maintain its desert springs pool character (although at a smaller size); 2) redirect flow into Pakoon Wash; 3) improve its native riparian habitat potential, emphasizing bulrush, seepwillow and Goodding's willow cover; 4) improve peripheral dry riparian honey mesquite and quailbush habitat; and 5) enhance colonization by paleosprings riparian *Isocoma*, *Sarcobatus*, and related vegetation in drier portions of the periphery; and 6) facilitate eliminating or greatly reducing nonnative bullfrogs and mosquitofish. Thus, Arena 4 will be maintained as a pool-dominated springs complex. Substantial discharge (ca. 50 gpm) flows to the east into Pakoon Wash, rather than out onto agricultural fields. This flow has transformed the wash into one of the longest perennial watercourses in Grand Canyon-Parashant National Monument, and has greatly enhanced wetland and riparian habitat along the course of the stream. The berms and other sources of fill around Arena 4 have been used to recontour the site and to begin recontouring the scraped and flattened agricultural fields immediately to the south. This should result in a more naturally sloping terrain that may be colonized by native desert shrubs and dryland riparian species (especially *Isocoma*).

The floor of the Arena 4 pool consists of unconsolidated silt and mud, up through which numerous small springs boil, and the pond is also fed by the larger springs complex at its northwest inflow channel. The pond deepens gradually from the shore, and cattails have densely colonized the shorelines and shallower water. A relatively large amount of flow arises from it, creating unstable footings for large equipment on parts of the berms. Prioritization of rehabilitation steps was necessary to accomplish the rehabilitation objectives, and were conducted in 2008 and 2009:

Step 1. Drain the pond and burn off the winter-dead cattails. These actions, conducted in the spring of 2008, exposed some of the pool bottom and shorelines, and revealed where safe footing existed for the large equipment needed to recontour the pond. Both actions were important for site evaluation.

Step 2. Reconstruct the pond overflow drainage system on the east edge of Arena 4. We recontoured the east side of the pond and filled the entire smaller pond system (arena 4 east). This was necessarily the first construction task, as we needed to begin rehabilitation in a headward fashion there. A channel was constructed to focus flow into Pakoon Wash to the east, and the smaller pond was in-filled to recreate a more natural geomorphology and to eliminate bullfrog habitat. This was completed by 15 June 2008. In 2009, the flow from Arena 4E began to develop a deep down cut. This was stabilized by creating several small rock dams on the steeper portion of the slope. This channel has now revegetated naturally, and joins with the flow from Arena 4 prior to entering Pakoon Wash.

Step 3. Complete and protect the pond drainage pipeworks. The agricultural pipeworks used to drain the pond were partially exposed in an unfinished cinderblock housing. In 2009 we completed the cover and the cinderblock walling around the drain, and recontoured the land around it. This provided a means of draining the pond in the future, while ensuring that the overall site is appropriately recontoured. These outflow works provide a way to manage the pond if additional reconstruction of the pond is needed. Eventually, the irrigation works may be removed, once they are no longer needed.

Step 4. Reduce the berms and recontour. In 2009, the berms were lowered to create a pool that is ultimately about 5-8’ deep. Local soil was excavated and used to fill selected pond areas, reshape the west and north slopes into the pond and to regrade the slope down to Pakoon Wash. Excess fill was added to the northwest corner of the agricultural fields immediately south of Arena 4.

Step 5. Develop an east-flowing overflow channel. In 2009, a neoprene and rock-lined 10’ wide and 3’ deep channel was constructed to carry overflow from Arena 4 to the east into Pakoon Wash. This step diverted the present flow back into Pakoon Wash, versus the pipe flow out onto the agricultural fields. The Arena 4 overflow channel starts at the northeast edge of the existing pool. It was lined with a pool liner and rock to prevent cattails from growing up through it. Approximately 1’ of rock and cobble was used to line this channel and to install small check dams on the steeper slope. This material was acquired from local sources near the site. The restored flowing reach in Pakoon Wash now regularly extends past the fence enclosure, which is approximately 0.5 miles from where Arena 4 enters Pakoon Wash.

Step 6. Nonnative bullfrog and mosquitofish control. Elimination of bullfrogs and mosquitofish from Arena 4 is being rigorously attempted using hunting, netting, and chemical control techniques. Installation of plastic 3’-tall frog fencing will be evaluated for around Arena 4. Such fencing could help contain existing frogs and limit subsequent recolonization.

Revegetation

The area surrounding the pond has been abundantly colonized by wetland vegetation, particularly cattail, within 1-3 yr. In 2009 and 2010, we planted rootstock of bulrush around the margins, recognizing that cattail is likely to colonize and take over those habitats in short order. Moist soil surfaces were revegetated with native wetland vegetation derived from local stock, including *Eleocharis, Schoenoplectus*, *Anemopsis,* and *Distichlis*. Wetland plugs were removed from other arenas or the stream habitat area and established at appropriate intervals in the heterogeneous habitat of Arena 4. *Baccharis* and *Salix gooddingii* have been pole planted along the lower, wetter portions of the new pond edges and the outflow channel to generate a transition from wetland to dryland riparian vegetation, in a design consonant with the available habitat. Peripheral and drier habitat were planted with Plucea sericea, Opuntia nr. phaecantha, *Isocoma, Sarcobatus, and Atriplex lentiformis*.

In 2009 and 2010, moist soil surfaces were planted with native wetland vegetation derived from local stock, including spikerush, bulrush, yerba-mansa, and saltgrass (*Distichlis*). Wetland plugs were removed from other arenas or the stream habitat area. Seepwillow and Goodding's willow were planted along the lower, wetter portions of the new pond edges and the outflow channel to generate a transition from wetland to dryland riparian vegetation, in a design consonant with the available habitat. The western hillslope were seeded with arrow weed, creosote, penstemon, purple sage, ragweed, indigo bush, range ratany, yucca, jimmyweed, four-wing saltbush, desert tobacco, globe mallow, snakeweed, brittlebush.

In 2010, pole plantings of Gooding's Willow and cottonwoods were planted along the eastern edge of the pond, to stabilize the hillslope and spread out the trees. Two rows of tree poles were made, one adjacent to the pond and the other 2 – 3 feet higher on the slope, with holes that reached moist soil. Additionally, Goodding's willow pole plantings and yerba mansa plugs were transplanted into the newly wetted soils in the eastern edge of the arena that developed since 2009. These plantings will help stabilize the downslope from the pond berm to Pakoon Wash.

Figure 4-23 Arena 4 prior to rehabilitation activities (25 August 2006). Photos of big pond. Left photo shows north end where flow was coming south (left side of photo) from Arena 3 into the big pond.

Figure 4-24 Arena 4 rehabilitation progress (06 June 2008) showing pond now drained, and formerly gently sloping inside edge of berm (along lower edge of right photo) was steepened/deepened to help maintain open water. Left photo shows significant new spring source that emerged in the area where Arena 3 formerly flowed into the big pond, after Arena 3 was breached and drained, and after the connection between Arena 3 and 4 was completely in-filled and remaining flow from Arena 3 spring sources emerged and was redirected to the east towards Pakoon Wash.

Figure 4-25 Arena 4 rehabilitation progress (July 2009), the image depicts the lowered berms and reduced open pond area. The cobble lined channel, created in 2009, allows flow from arena 4 toward Pakoon wash, and is shown in the close up photos. The re-contoured western hill-slope is also depicted, which obliterated the agricultural road, and now provides a gradual slope, matching the hill's contours.

4.8.9 Arena 5 – site specific information

Pre-existing conditions

Arena 5 is a paleosprings portion of the Pakoon Springs rehabilitation site, and lies immediately north of "Mt. Pakoon" (Fig. 4-12). It is shown on the U.S. Geological Survey 7.5' map of the site to have been a flowing springs prior to about 1950, but obviously has not flowed in recent decades, or perhaps even in recent centuries. It has been partially modified by having been graded, but its basic geomorphology as a paleosprings remains mostly intact. The vegetation covering it includes honey mesquite and quailbush, with catclaw at the lowest elevations, and desert shrub species, particularly creosote-bursage at its upper edges.

Rehabilitation methods and plans

The desired future condition of Arena 5 was to restore its appearance as a terraced paleosprings. This was accomplished in 2008 by recontouring the arena into a gently terraced, smoothly contoured surface, with the potential to accommodate desert and paleosprings vegetation, particularly *Isocoma*, mesquite, and quailbush. The primary objective for this arena was to recontour it in a fashion compatible with the surrounding landscape. Vigorous, natural regrowth and seed production of existing vegetation on Arena 5 reduced the need to reseed it seasonally with local native stock. Only vegetation monitoring was done in Arena 5 in 2009 and 2010.

Revegetation

As no flow emerges from the site and plantings were unlikely to survive without irrigation , we monitored natural recruitment on this recontoured site by *Isocoma*, *Sarcobatus*, *Atriplex lentiformis* and *A. elegans*, and sought but did not find *Prosopis glandulosa* seedlings

4.8.10 Rehabilitation conclusions

Rehabilitation of Pakoon Springs has enlarged and enhanced one of the largest springs complexes on the Arizona Strip, and created the longest perennial stream in Grand Canyon - Parashant National Monument. The results of progress in implementation have been better than expected with springs re-emerging as hoped after infilling of excavated ponds and surprising natural recolonization with spikerushes, yerba-mansa, datura, bulrush, Goodding's willow, seep willow, cottonwood, and other native plant species. The project has surpassed expectations for wetland plant recolonization and abundance.

Challenges still remain with nonnative species: bullfrogs, mosquitofish, Russian thistle, yellow star thistle, Bermuda grass, brome, cheat grass, tamarisk, etc. Future planting and nonnative species control activities will be necessary.

4.9 Photo comparisons, before and after

In the course of photo-documenting the hydrologic monitoring activities, some startling before and after rehabilitation comparisons were captured. Below is a series of comparison photos taken at three distinct monitoring locations (Figs. 4-26 to 28). In the last comparison, the 2010 photo is taken from a distance and the monitoring location is in the center of the thicket behind the field gear.

Figure 4-26 Comparison 1: April 2008 versus August 2010

Figure 4-27 Comparison 2: April 2008 versus August 2010

Figure 4-28 Comparison 3: April 2008 versus August 2010

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Project conclusions

When deeper springs sources have not been damaged or modified, springs ecosystem geomorphology and habitat rehabilitation or rehabilitation can be accomplished. Appropriate stewardship and multiple use sustainability are critical foci of the missions of the BLM, the National Forest Service, other federal lands, and many state, local, and private managers. With critical funding assistance from the Arizona Water Protection Fund, the BLM and GCWC have restored the Pakoon Springs ecosystem from a highly modified and degraded condition to one in which natural ecosystem processes prevail. This effort is regarded by the BLM as one of the premier examples of successful partnership to achieve agency goals. While monitoring and additional work remains to be accomplished at Pakoon Springs, this project has clearly demonstrated that collaborative partnerships focused on clear, well-defined goals and rigorous implementation and monitoring can be used to improve ecosystem sustainability and stewardship, even for highly degraded springs. Part of the success of this project was attributed to improving understanding of site history and pre-treatment condition, and carefully planning and implementing management actions. The stewardship formula of:

Inventory → Assessment → Planning → Implementation → Monitoring with feedback

Was pursued rigorously through this project, and its applicability was clearly demonstrated by the success of this project.

5.2 Evaluation of project success

The primary means of evaluating the success of this project was through successful fulfillment of the 9 project tasks, the last of which is this final report. Each of the tasks was completed, with draft and final reports submitted to AWPF (see Section 2.5, and the Results section).

5.3 Recommendations for future rehabilitation activities

While the pilot feasibility rehabilitation study of the Pakoon Springs has been tremendously successful, additional riparian rehabilitation activities are needed. For example, leveling of agricultural fields by previous landownders forced Pakoon Wash to the east, severely narrowing the channel, and it is eroding into the hillside. While we restored flow to Pakoon Wash, , the geomorphology of the stream channel in the upper reaches remains strongly influenced by this agricultural leveling. Ecosystem services and functions that can be restored by stabilizing channel linkages and recontouring Pakoon Wash terraces include: erosion control and sediment retention, disturbance regulation, water regulation, riparian, wetland, and stream habitat rehabilitation, and soil protection. Non-native species management and removal should be continued, and assessment and implementation of reintroduction or translocation of rare local species are needed to create refugia for native and migratory species. Lastly, since rehabilitation activities began, visitation has increased at Pakoon Springs. The project site is becoming more visible from the road, as the amount of lush, bright green riparian vegetation increases, providing a lush contrast to the harsh Mojave desert habitat surrounding the project area. Potential increased public use of this very remote site has created the need for focused management of the public use to protect newly established wetlands and the perennial stream habitats and to ensure rehabilitation investments.

The following recommendations on future rehabilitation are likely to improve the long-term sustainability of Pakoon Springs:

- Restore riparian vegetation and habitat and mitigate flood potential in Pakoon Wash through channel and stream-bed erosion and headcut stabilization. This can be accomplished by stabilizing channel linkages between the restored springs and the rewatered perennial section of Pakoon Wash. We suggest recontouring to relink the channel in Pakoon Wash to its floodplain, opening up the severely narrowed channel, and creating a braided stream morphology to minimize the impacts of floods and expand/restore riparian habitat, as well as completing recontouring and revegetation of riparian terraces.

- Reduce negative impacts of nonnative species. In particular, efforts to remove nonnative plants, bullfrogs and mosquito-fish should be continued to improve habitat for native species.

- Develop and implement a monitoring program for long-term monitoring and assessment of habitat needs. Such an effort should include monitoring of multiple trophic components of the ecosystem, including hydrology, riparian vegetation, insects, birds, small mammals.

- Plan, prepare for, and translocate high priority native species, as determined through interagency planning.

- Develop and implement a recreation plan and educational trail system to protect wetlands and stream crossings. This will improve visitor experience, and eductional outreach to the growing number of visitors to the site.

The BLM and Grand Canyon Wildlands Council, Inc. are committed to the long-term, collaborative stewardship of Pakoon Springs, and will continue to seek funding and support to implement these recommendations.

6 ACKNOWLEDGEMENTS

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7 APPENDICES

(electronic and hardcopy format)

7.1 Oral history –see attached hardcopy

7.2 Permits and authorizations –on file with AWPF

7.3 GIS coordinates and area values

Table 7-1 Soil Core sample locations

ID	Easting	Northing	Latitude	Longitude
180	18567.57695	9596.266409	36.41261	-113.95878
181	18776.49047	9595.815295	36.41261	-113.95807
182	18985.40398	9595.365718	36.41261	-113.95736
184	19615.09469	9597.660345	36.41262	-113.95522
185	19615.09469	9597.660345	36.41262	-113.95522
198	18568.03366	9807.409383	36.41319	-113.95878
199	18776.94562	9806.958266	36.41319	-113.95807
200	18985.85758	9806.508685	36.41319	-113.95736
201	19194.76954	9806.060641	36.41319	-113.95665
203	19615.53587	9805.162908	36.41319	-113.95522
216	18565.5401	10014.91835	36.41376	-113.95879
217	18777.39293	10014.46086	36.41376	-113.95807
218	18986.30337	10014.01128	36.41376	-113.95736
219	19195.22159	10017.20363	36.41377	-113.95665
220	19407.0744	10016.75084	36.41377	-113.95593
221	19615.9848	10016.30589	36.41377	-113.95522
234	18565.99684	10226.06136	36.41434	-113.95879
235	18777.8481	10225.60387	36.41434	-113.95807
236	18986.75698	10225.15429	36.41434	-113.95736
237	19195.66586	10224.70624	36.41434	-113.95665
238	19404.57474	10224.25972	36.41434	-113.95594
239	19616.42599	10223.80849	36.41434	-113.95522
252	18566.44571	10433.564	36.41491	-113.95879
253	18775.36092	10436.75325	36.41492	-113.95808
255	19196.11793	10435.84926	36.41492	-113.95665
254	18987.2106	10436.29731	36.41492	-113.95736
256	19405.02525	10435.40275	36.41492	-113.95594
257	19616.87493	10434.95151	36.41492	-113.95522
270	18569.8448	10644.70069	36.41549	-113.95878
271	18775.80827	10644.2559	36.41549	-113.95808
272	18987.65641	10643.79997	36.41549	-113.95736
273	19196.56221	10643.35191	36.41549	-113.95665
274	19405.47577	10646.54579	36.4155	-113.95594
275	19614.38154	10646.10081	36.4155	-113.95523
288	18567.35923	10855.85013	36.41607	-113.95879
289	18776.26348	10855.39897	36.41607	-113.95808
290	18985.16773	10854.94936	36.41607	-113.95737
291	19197.01429	10854.49498	36.41607	-113.95665
292	19405.91853	10854.04846	36.41607	-113.95594
293	19614.82277	10853.60347	36.41607	-113.95523
306	18567.80812	11063.35282	36.41664	-113.95879
307	18776.71085	11062.90167	36.41664	-113.95808
308	18985.61357	11062.45205	36.41664	-113.95737
309	19197.46637	11065.63807	36.41665	-113.95665
310	19406.36906	11065.19154	36.41665	-113.95594
311	19615.27175	11064.74655	36.41665	-113.95523
324	18568.2649	11274.49594	36.41722	-113.95879
325	18777.16607	11274.04478	36.41722	-113.95808
326	18986.06724	11273.59516	36.41722	-113.95737

327	19194.9684	11273.14707	36.41722	-113.95666
328	19406.81183	11272.69425	36.41722	-113.95594

Table 7-2 Hydrologic feature locations

ID	Elevation (ft)	Northing	Easting
1	900.94	10880.96	18948.65
2	905.47	10862.41	18974.8
3	894.3	10656.12	18874.92
4	892.29	10606.57	18963.88
5	892.29	10652.24	18999.11
6	892.19	10480.25	19041.69
7	885.07	10409.73	19239.87
8	880.61	10333.65	19312.44
9	877.42	10246.94	19271.15
10	893.68	10918.45	18692.85

Table 7-3 Pakoon Springs vegetation POLYGON DESIGNATIONS (collected during ground-truthing on 17-18 March 2007). Polygon IDs refer to field mapping sheets.

Cover Type	Key Number	Area (ac)	Area (ha)	Polygon ID Number
Agricultural Field	1	5.32	2.15	3
Agricultural Field	1	3.65	1.48	4
Arroyo	2	0.22	0.09	5
Arroyo	2	0.29	0.12	6
Junk Pile	3	0.01	0.00	7
Junk Pile	3	0.09	0.04	8
Junk Pile	3	0.04	0.02	9
Junk Pile	3	0.09	0.03	10
Junk Pile	3	0.06	0.02	11
Low Gradient Desert Scrub	4	0.00	0.00	12
Low Gradient Desert Scrub	4	0.18	0.07	13
Low Gradient Desert Scrub	4	0.21	0.08	14
Low Gradient Desert Scrub	4	0.36	0.14	15
Low Gradient Desert Scrub	4	3.79	1.53	16
Low Gradient Desert Scrub	4	0.05	0.02	17
Low Gradient Desert Scrub	4	0.12	0.05	18
Low Gradient Desert Scrub	4	0.33	0.13	19
Low Gradient Desert Scrub	4	3.30	1.34	20
Open Water	5	0.28	0.11	1
Paleospring Scrub	6	0.74	0.30	21
Paleospring Scrub	6	0.49	0.20	22
Paleospring Scrub	6	1.01	0.41	23
Paleospring Scrub	6	0.67	0.27	24
Paleospring Scrub	6	0.12	0.05	25
Paleospring Scrub	6	0.01	0.01	26
Paleospring Scrub	6	0.12	0.05	27
Paleospring Scrub	6	1.38	0.56	28
Paleospring Scrub	6	1.57	0.64	29
Paleospring Scrub	6	7.02	2.84	30

Riparian	7	0.02	0.01	31
Riparian	7	0.01	0.00	32
Riparian	7	0.01	0.00	33
Riparian	7	0.00	0.00	34
Riparian	7	0.00	0.00	35
Riparian	7	0.01	0.00	36
Riparian	7	0.01	0.00	37
Riparian	7	0.00	0.00	38
Riparian	7	0.01	0.00	39
Riparian	7	0.00	0.00	40
Riparian	7	0.00	0.00	41
Riparian	7	0.11	0.04	42
Riparian	7	0.22	0.09	43
Riparian	7	4.53	1.83	44
Riparian	7	0.53	0.22	45
Riparian	7	0.02	0.01	46
Riparian	7	0.01	0.00	47
Riparian	7	0.01	0.00	48
Riparian	7	0.01	0.00	49
Riparian	7	1.20	0.49	50
Riparian	7	0.02	0.01	51
Riparian	7	0.01	0.00	52
Riparian	7	0.02	0.01	53
Riparian	7	0.26	0.11	54
Riparian	7	0.29	0.12	55
Riparian	7	0.03	0.01	56
Riparian	7	0.22	0.09	57
Riparian	7	0.02	0.01	58
Riparian	7	0.32	0.13	59
Riparian	7	0.32	0.13	60
Riparian	7	0.05	0.02	61
Riparian	7	0.07	0.03	62
Riparian	7	0.17	0.07	63
Riparian	7	0.32	0.13	64
Riparian	7	0.21	0.09	65
Road	8	0.58	0.23	66
Road	8	0.01	0.00	67
Road	8	0.05	0.02	68
Road	8	0.14	0.06	69
Road	8	1.45	0.59	70
Road	8	2.33	0.94	71
Road	8	1.97	0.80	72
Rocky Slope	9	4.60	1.86	73
Rocky Slope	9	2.08	0.84	74
Shed	10	0.00	0.00	2
Wetland	12	0.17	0.07	75
Wetland	12	0.46	0.19	76

Wetland	12	1.18	0.48	77
Wetland	12	0.18	0.07	78
Wetland	12	0.27	0.11	79

7.4 Data –attached on CD

7.4.1 Hydrology

- Raw data provided electronically only, Microsoft Excel
- Laboratory analysis of water quality, provided in Adobe portable document format (PDF)

7.4.2 Soils

- Raw data provided electronically only, Microsoft Excel

7.4.3 Plants

- Raw data provided electronically only, Microsoft Excel

7.5 Maps and photos

- Maps, rehabilitation plans (11X17 hardcopy)
- Field rehabilitation photographs (910 on DVD)