Final Report
Task #9

Montezuma Well Riparian Restoration Project

Montezuma Castle National Monument,
Montezuma Well Unit, AZ

AWPF Project #: 08-161

Natural Channel Design, Inc.

February 2014

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<u>Submitted to:</u>
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The views or findings presented are the Grantee's and do not necessarily represent those of the Commission, the State, or the Arizona Department of Water Resources.

Natural Channel Design, Inc. wishes to express its gratitude to the National Park Service and the Arizona Water Protection Fund for their support of this project. We would especially like to thank Michelle Girard, Kathy Davis, Sharon Kim, Dennis Casper and Rodney Held for their vision, leadership and commitment. Without them and the help of many volunteers this project could not have been a success.

This FINAL REPORT is dedicated to the memory of Tom Moody, founder of Natural Channel Design, and NCD staff members Michael McCrea, Dick Farnell, Mark Wirtanen, Russ Lyman, Allen Haden, Cathy Scudieri, Stephanie Yard and the late Tom Yard and Matt Roberts; all of which spent countless hours towards successful implementation of this worthwhile project.

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EXECUTIVE SUMMARY

The final report of the Montezuma Well Riparian Restoration Project summarizes each step of the project from its commencement to completion. The report is organized into Background, Inventory and Assessment, Design, Construction and Implementation, Monitoring, and Public Outreach. At the end of the report, a Lessons Learned section summarizes stumbling blocks, modifications, or successes that occurred while working six years to complete this worthwhile restoration project.

The project site lies at 3,500 feet elevation within the Montezuma Well Unit of Montezuma Castle National Monument. The site had once been an old homestead and the abandoned fields had been overgrown with invasive species. The goals of the project were to: 1) restore and enhance riparian vegetation/habitats by managing invasive weedy species and replacing them with native species, 2) reconnect the riparian habitats by creating a more natural transition community on the upland terrace between Wet Beaver Creek and the irrigation ditch, 3) restore and enhance the riparian, desert bosque, and grassland habitats and, 4) provide educational opportunities for Monument visitors regarding the importance of riparian plant communities and their habitats. AWPF grant project tasks included:

Task 1: Permits, Clearances, Authorizations, Agreements
Task 2: Development of Plans
Task 3: Development of Final Design Plans
Task 4: Non-native and Invasive Weed Management
Task 5: Irrigation Water Management
Task 6: Revegetation and Wildlife Improvements
Task 7: Conduct Monitoring
Task 8: Public Outreach Implementation
Task 9: Final Report

The contract was awarded in 2008 and the project completed in 2013. Starting in 2008, weed management began and included mowing and herbicide application. These strategies have proven effective on most targeted species and continued through 2013. The plant irrigation consisted of gas powered pumps supplying a drip irrigation and sprinkler system. The initial work on installing the irrigation began in 2009. Modifications and additional lines were added throughout 2011 and operated through 2013. Two major planting efforts were conducted. The first began in 2010 with planting of over 800 containerized plantings and sowing over 150 lbs of native grass seed. A second planting effort was undertaken in 2011 with an additional 1,200 containerized plantings and more grass seeding. The Park continued to seed smaller areas with locally collected seed in 2012.

Monitoring of the project began in 2008 and continued through 2012. Monitoring consisted of surveying random one square meter plots along three 900 foot transects crossing the project area. Vegetation type and density along with the occurrence of noxious weeds was recorded at each plot. In addition to the vegetation transects, ten photo points were established and the photos re-taken each year during monitoring.

The project site has responded well to the applied restoration practices. The density of noxious weeds, with the exception of nightshade, has been significantly reduced. Native grasses are established in fields that had only weeds prior to the project. Surviving containerized plantings are becoming established, and some have begun to produce seed. The project is well on its way to becoming a functioning upper riparian community.

The final report of the Montezuma Well Riparian Restoration Project summarizes each step of the project from its commencement to completion. The report is organized into Background, Inventory and Assessment, Design, Construction and Implementation, Monitoring, and Public Outreach. At the end of the report, a Lessons Learned section summarizes stumbling blocks, modifications, or successes that occurred while working six years to complete this worthwhile restoration project.

BACKGROUND

PROJECT DESCRIPTION

The Montezuma Well Unit of Montezuma Castle National Monument (Monument) is located along Wet Beaver Creek, a tributary to the Verde River, in central Arizona (Figure 1). The unit was incorporated into the Monument in 1943 to preserve and protect the unique geology and hydrology, as well as the prehistoric and historic significance of the area. Water from Montezuma Well exits above river level and flows along the northern border of the flood terrace in an historic irrigation ditch; eventually converging with Wet Beaver Creek downstream of the Monument boundary.

The project area includes approximately 40 acres of flood terrace along Wet Beaver Creek. The terrace is inundated infrequently by large flood events and typically supports a diverse dry riparian plant community consisting of mesquite bosque and open grassland that complement the more lush vegetation along Wet Beaver Creek. Flood terraces throughout the project area have been heavily impacted by agricultural practices and had been overrun by dense infestations of non-native weed species. This project will enhance the mesquite bosque habitat along Wet Beaver Creek by managing nonnative weeds and water delivery to the site and by planting appropriate native vegetation. The project will restore valuable wildlife habitat along Wet Beaver Creek and improve water quality by reducing erosion and sediment carried into Wet Beaver Creek during storm events.

The purpose of this project is to: 1) restore and enhance riparian vegetation/habitats by managing invasive weedy species and replacing them with native species, 2) reconnect the riparian habitats by creating a more natural transition community on the upland terrace between Wet Beaver Creek and the irrigation ditch, 3) restore and enhance the riparian, desert bosque, and grassland habitats which are declining and fragmented in other regional streams, and 4) to provide educational opportunities for Monument visitors regarding the importance of riparian plant communities and their habitats. Achieving project goals of reestablishing a variety of diverse native vegetation will require the use of temporary irrigation. The irrigation ditch along the northern border of the project area will be repaired and used to provide temporary irrigation for planted vegetation. The planned enhancements are expected to directly benefit riparian wildlife species, including the Lowland leopard frog *(Rana yavapaiensis)* that has been documented in the irrigation ditch.

The project is a cooperative venture between the National Park Service (NPS) Montezuma Well National Monument and Natural Channel Design, Inc (NCD). NCD is the grantee providing technical and grant management services while the NPS is the land manager providing labor, materials and design guidance as needed.

PROJECT OBJECTIVES

Project objectives focus project activities and provide measurable goals to judge project success. The objectives for this project are straightforward and address flood terrace characteristics, riparian vegetation communities, wildlife habitat characteristics, and public outreach. Project objectives are:

- Manage invasive and non-native plant species to promote native riparian vegetation and habitats.
- Restore/protect the riparian, transitional mesquite bosque, and grassland communities on the flood terrace between riparian wetland and desert ecosystems. The expanded riparian corridor will provide important wildlife habitats that are otherwise missing in this area.
- Enhance public educational opportunities for Monument visitors through the restoration of the riparian flood terrace.

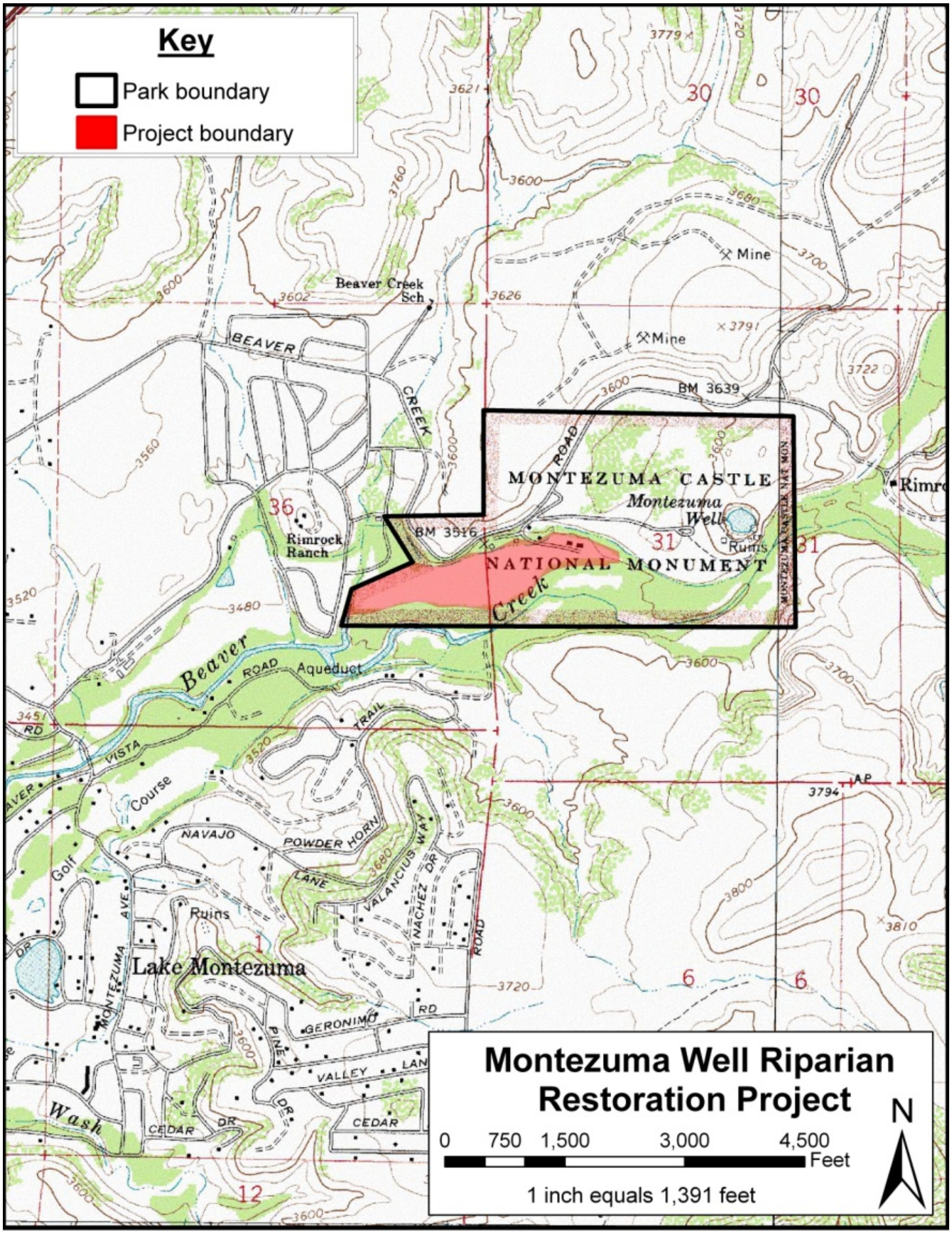

Figure 1. Project Site Location

PROJECT TIMELINE

Table 1. Project timeline

Year	Month	Task
2008	April	AWPF Final Contract
2008	October	Initial Weed Management
2009	February	Final Design Completed
2010	March	Initial Plantings Installed
2010	April	Initial Irrigation System Installed
2011	February	Public Outreach Event
2011	March	2nd Plantings Installed
2009-2013	Ongoing	Weed Management
2012	September	Final Monitoring
2014	January	Final Report

PROJECT APPROACH

Restoration of the altered flood terraces are the focus of this project. Terraces are generally old floodplains abandoned when channel elevations are lowered by incision or surfaces are aggraded by sediment deposition during high flow events. There are commonly two levels of terrace largely differentiated by inundation frequency. Low terraces can be expected to be flooded by moderate, infrequent floods (~ 10 to 25-year). High terraces are flooded by high and extreme floods (25 to 100-year). The focus of this project is on the high flood terrace and its connection to Wet Beaver Creek.

An empirical design approach was used for this project. This approach seeks to identify “natural or reference” conditions and compare them to existing project site conditions to determine the potential of the system. From this comparison, a set of tasks were identified to move the existing conditions to the desired reference conditions. The existing flood terrace vegetation, soils, and topography were characterized including its associations with adjacent floodplain and upland habitats. Reference conditions were identified within undisturbed local areas and/or through available literature. The most useful reference conditions existed within the Wet Beaver Creek stream corridor near the project site.

The existing irrigation system along the northern border of the project area is required to temporarily irrigate plantings for establishment. The condition of the ditch was assessed to locate any areas in need of maintenance or repair to ensure water delivery to the project.

PART I: INVENTORY AND ASSESSMENT

The entire project is located on approximately 40 acres of flood terrace that are being restored to native riparian flood terrace habitat. Prior to assessment, the project site was divided into five parts based upon existing vegetation, management, and restoration potential. These sites include the picnic area, riparian buffer zone, West, Central, and East fields (Figure 2). Inventory data was gathered from various sources including government agency reports, aerial photography, previously collected topographic surveys, topographic surveys and vegetation surveys conducted by Natural Channel Design in cooperation with the National Park Service.

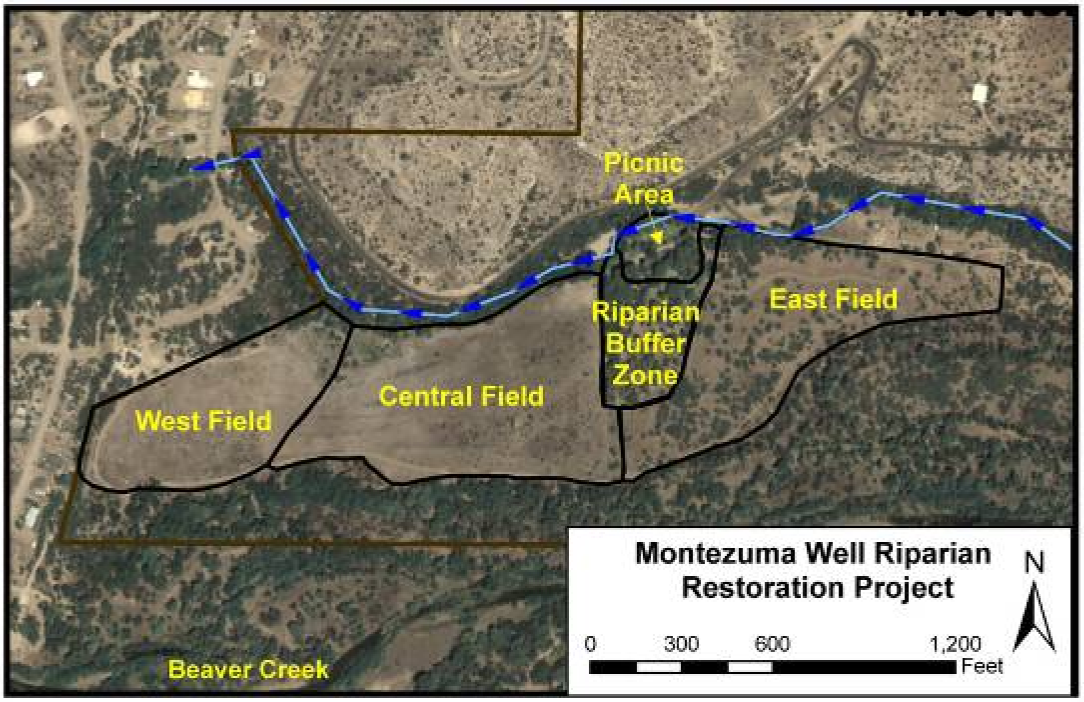

Figure 2. Overview of the project area showing field delineation.

Detailed topographic surveys provide a baseline for project planning and management. Several sources of information were gathered and integrated to provide a complete topographic survey of the project site. An existing aerial topographic survey completed by Western Mapping Company in early 2007 utilizing 2006 aerials to photogrammetrically create a base topographic map. This map was augmented by ground surveys of the irrigation infrastructure and other critical areas by Natural Channel Design, Inc during the summer of 2008 to provide a complete and detailed topographic map of the existing landforms within the project site. Aerial photographs, taken in June 2007, were obtained from the Arizona State Cartographers Office Arizona Imagery Server and superimposed on the topographic map to provide visual reference.

CLIMATE

The following evaluation of climatic conditions for the Montezuma Well Unit were based on data collected by the National Weather Service at stations at Montezuma Castle National Monument and at the Beaver Creek Ranger Station (1915-2007) obtained from the Western Region Climate Center (WRCC) website. Since the project area lies about halfway between these two stations with regard to both elevation and location, the estimates are determined as means from the two stations. The climate of the project area is typical of mid-elevation Arizona. Summer high temperatures can be over 100° F; winter low temperatures can be below freezing. Frost-free period ranges from 150 to 180 days. The site is considered arid with most precipitation falling in the form of rain. Climatic data is given in Table 2. The plant species included in the planting design were drought tolerant with a minimum tolerable annual rainfall of 10 inches. A weather station was installed at the project site in early December 2008 in the central field. The station provides accurate precipitation and temperature data from the site rather than many miles away.

Table 2. Climate data; Montezuma Well Unit
The mean annual precipitation is 14 inches. Of this total, 3.8 inches, or about 27 percent, usually falls in the summer. The driest period is from April through June.

CLIMATE DATA	Montezuma Well Average Estimate		Montezuma Castle NM Station #: 25635 1938 - 2007		Beaver Creek Ranger Stn Station #: 20670 1915 - 2007	
Mean Annual Precipitation	14.00	in.	12.90	in.	15.10	in.
Mean Annual LOW Precipitation	5.52	in.	3.52	in.	7.52	in.
Mean Winter Precipitation	3.80	in.	3.48	in.	4.12	in.
Mean Spring Precipitation	2.50	in.	2.22	in.	2.78	in.
Mean Summer Precipitation	3.84	in.	3.80	in.	3.88	in.
Mean Fall Precipitation	3.86	in.	3.41	in.	4.31	in.
Mean Annual Temperature	61.55	°F	61.50	°F	61.60	°F
Mean January Temperature	43.40	°F	43.00	°F	43.80	°F
Mean July Temperature	82.20	°F	82.40	°F	82.00	°F
Mean Growing Season	Apr 1 - Oct 31					

HYDROLOGY AND HYDRAULICS

The purpose of this assessment was to characterize the relationship between the flood terrace project area and Wet Beaver Creek. The information was used to inform planting design. The assessments included a determination of the contributing watershed, an estimate of the range of flood flows and their probability, and the potential for these flows to impact and/or inundate the project flood terraces.

WATERSHED DELINEATION

Wet Beaver Creek at the project site has a total watershed area of approximately 192 square miles (Figure 3). The stream originates along the southern edge of the Colorado Plateau on the Mogollon Rim at an elevation of 6,200 feet in the Beaver Creek Wilderness Area and enters the Verde River, approximately 25 miles downstream, at 3,000 feet. The stream is perennial and unregulated with the exception of minor baseflow diversions above the project site. The watershed area above the Mogollon Rim is dominated by Ponderosa Pine forest. The lower watershed drains more arid ecosystems such as pinon-juniper woodlands and desert shrublands. The creek has a robust riparian plant community including cottonwoods, sycamores, and alders.

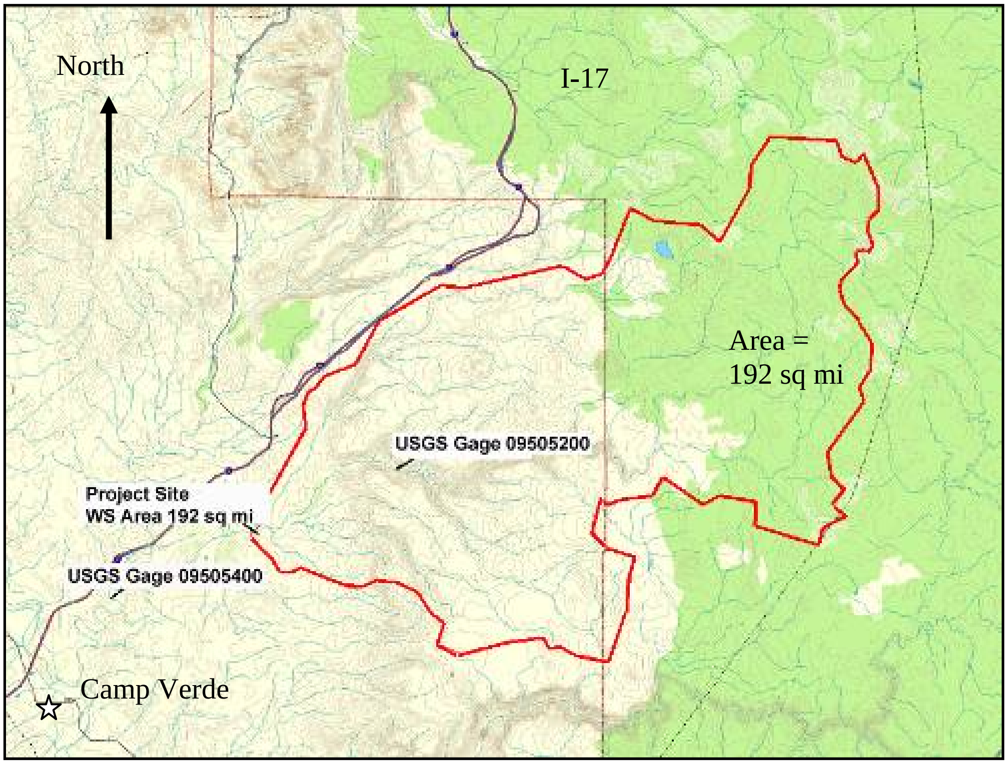

Figure 3. Watershed area for the project site

HYDROLOGY

Project hydrology was characterized by estimating discharges for various recurrence intervals (RI) using an analysis of flood frequency. Recurrence interval is the probability of a flood of a certain magnitude or greater will occur. The most accurate method to evaluate flood frequency is through the direct use of stream flow data at the site. However, often this data is not available and other methods using data from nearby gages is used to create regional discharge relationships. There is no stream flow data from Wet Beaver at the project site. A gage upstream of the site has a long record (#9505200 Wet Beaver Creek Near Rimrock), but the drainage area of 111 square miles is substantially smaller than the drainage area of the project site (192 sq mi). Another gage downstream has an inadequate period of record to develop flood frequencies.

A combination of methods was used in this analysis. First, flood discharges at the upstream gage were scaled up by the increase in watershed area. This method has the potential to overestimate discharges since the majority of precipitation originates in the upper watershed. Secondly, the NRCS regional hydrology method, regression equations based on watershed areas generated from nearby gages, was used to estimate discharges (SCS 1972). Seven local gage sites with relatively long flow records provide a robust data set and increases confidence in these results. Finally, regression equations developed by USGS based on watershed area and mean watershed elevation under the National Flood Frequency (NFF) program was used for comparison (USGS 2002). These discharge values are based on 68 regional gage stations but have standard errors ranging from 37% to 105% depending on the discharge. The estimates varied in magnitude and an average of all three was used for the project area. The discharge from each model and estimate for the project are shown in

Table 3.

Table 3. Estimated discharges for Wet Beaver Creek at the project site.

Method	Estimated Discharge 1.5 -year (cfs)	2-year (cfs)	5-year (cfs)	10-year (cfs)	25-year (cfs)	50-year (cfs)	100-year (cfs)
Scaled WS area	2,422	4,151	10,378	15,741	24,216	31,135	36,324
NRCS Reg Hydrology	1,692	2,985	8,156	13,313	22,165	29,558	39,255
NFF program	638	1,120	4,790	7,850	13,500	19,800	27,300
Project Site Estimates	1,600	2,700	7,800	12,300	20,000	27,000	34,000

CHANNEL HYDRAULICS

A channel cross-section and longitudinal profile of Wet Beaver Creek were surveyed and used to model water surface elevations for various flood events. The purpose was to determine the discharge and frequency of flood flows that overtop and spread across the project area. A moderate flood of approximately 6,000 cfs (~ 5-year RI) during the previous winter deposited a distinct debris line along the creek. This flow did not inundate the project area but was used to calibrate the model.

The creek is a medium gradient, cobble bed, meandering stream with a well-vegetated floodplain adjacent to the project area. The average gradient is 0.011 ft/ft (1.1%). WinXSPro, a cross-section analyzer developed by the Bureau of Land Management and USDA Forest Service (USFS 2005) was used to model water surface elevations (stage) and mean velocities for the estimated Wet Beaver Creek discharges. A representative cross-section was surveyed across Beaver Creek near the boundaries of the Central and East fields.

The model results were calibrated by two known stages; bankfull stage that was identified during the survey and the winter 2008 flood debris line. The model results suggest that flows begin to spread across the project flood terrace only during high flow events with recurrence intervals between 25- and 50-years (Figure 4). This is consistent with the NPS staff observations that during the 1993 floods, a 50-year event, part of the eastern field portion of the project area was inundated.

The results of this analysis offer two other insights: 1) the project area appears to lie well above Ordinary High Water as defined in the Clean Water Act and a 404 permit was not needed from the Army Corps of Engineers and 2) the combination of the elevation difference between perennial flows and the flood terrace and the infrequent inundations, the creeks influence on groundwater levels across the terrace is minimal. As a result, the planting design should be limited to those species that can be supported by precipitation alone, need not be connected to a groundwater table, and can withstand infrequent inundations.

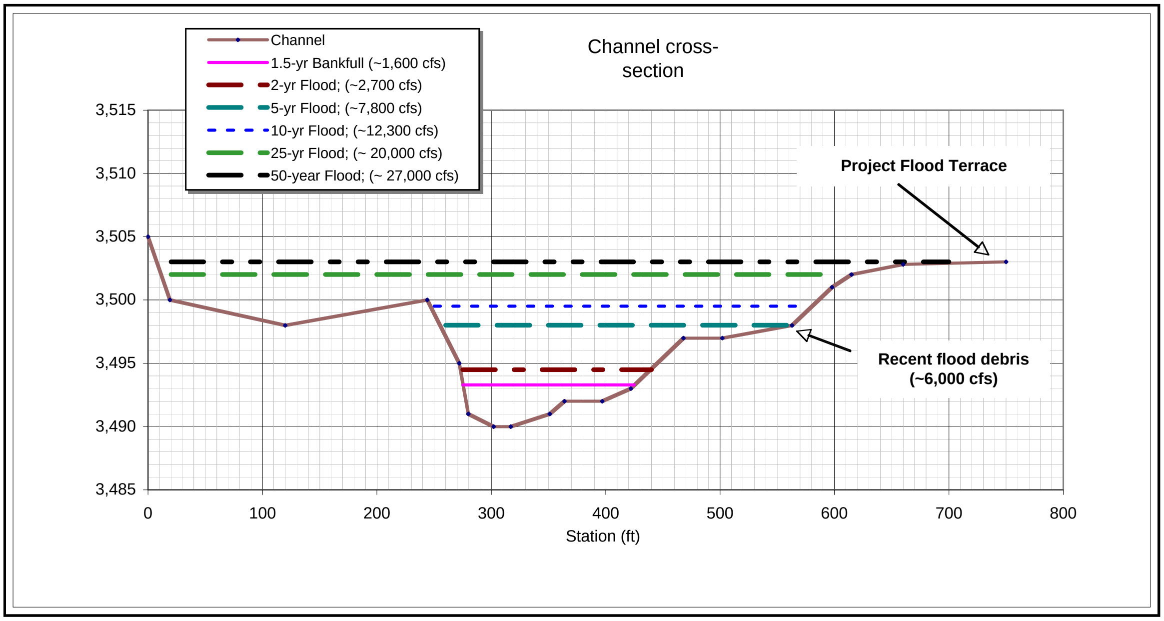

Figure 4. Representative cross-section, stage-discharge relationship

The Win-XSPro hydraulic model was calibrated against the woody debris deposited by a recent 2008 flood. The model results suggest that the project flood terrace area is inundated infrequently at 25- to 50-year recurrence intervals.

SOILS

Soil Survey Data

The purpose of this analysis was to determine the existing soil texture and other characteristics to inform the planting design. General information on the soils of the Montezuma Well Unit is published in Soil Survey of Montezuma Castle National Monument, Arizona (including Montezuma Well), USDA Natural Resources Conservation Service, 1999 (Lyndsay, 1999). Additional on-site soil surveys were conducted in 1993 by the USDA Soil Conservation Service. To augment this general data, site specific soil samples were collected by NCD and analyzed by the laboratory at Utah State University.

The project site is divided into six soil map units (Figure 5) that fit into two soil subgroups, Ustic Torrifluvents and Typic Hydraquents. They are slightly, to moderately alkaline. Calcium carbonate makes up 0-5% of the soil chemistry, likely from being irrigated from the calcium carbonate rich water that flows from the well. Mean annual soil temperature ranges from 60-65 degrees Fahrenheit. The potential rooting depth is more than 60 inches for all project area soils.

The Ustic Torrifluvents are soils that have an aridic moisture regime (648 Riveroad gravelly silt loam, 649 Riveroad loam, 650 Riveroad clay loam). These are very deep, well drained mixed alluvium found on floodplain terraces with 0-2% slopes that are rarely flooded. The soil pH ranges from 7.4 to 8.4 and the clay content ranges from 15-35%. The Typic Hydraquents soils are thought to be artifacts of the many years of irrigation on the West side (651 Feps fine sandy loam and 652 Feps loam). These are very deep, poorly drained mixed alluvium found on floodplain terraces with frequent irrigation induced flooding. The soil pH ranges from 7.9 to 9.0.

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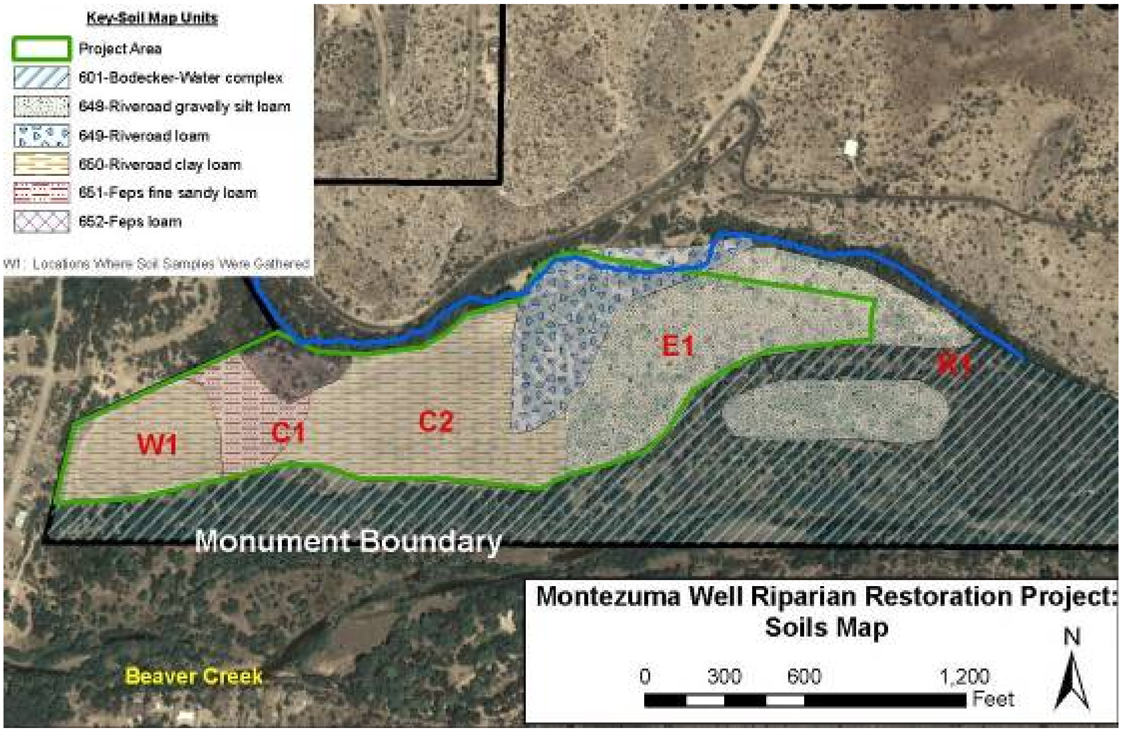

Figure 5. Soil map units in the project site.

Soil map units from 1999 Soil Survey, USDA-NRCS. Five mixed grab samples were collected and analyzed at Utah State University Analytical Labs.

Soil Sampling Data

Five soil samples were collected within the project area (Figure 5 and Table 4) and sent to the Utah State University Analytical Labs for analysis. Each grab sample consisted of four mixed core samples taken at about 1 foot depth. Samples were analyzed for alkalinity, salinity, organic matter, and available nutrients. For optimum plant growth, the soil must be capable of storing nutrients and transferring them to the root surface for plant uptake. Nutrients included nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S); trace elements include iron (Fe), manganese (Mn), copper (Cu) and zinc (Zn). Soil test results indicated that the reference and eastern field samples have lower organic matter, and lower nitrogen. This variance may be due to several factors: these areas have been non-irrigated for over 60 years; little management activities, such as mowing, have taken place; and native tree and shrub species are established with approximate 50% canopy cover. It was hopeful that soil health can be improved on the remaining fields by restoring the landscape with native plants.

Arsenic analyses were conducted on four samples (C1, C2, E1 and Ref1). Two samples were taken in the central/west field (C1). Research indicates that normal background concentrations in soil can be 1 to 40 mg/kg (ppm). The well water has very high levels of arsenic naturally occurring, greater than 100 ppb (UofA 2001). There are chemical similarities between arsenic and phosphorous; arsenic has been observed to substitute for phosphorus (Assembly of Life Sciences, 1977). Arsenic may upset plant metabolism and interfere with normal plant growth. The field samples had considerably higher levels of arsenic than the reference site. It was expected that due to the low elevation and long-term irrigation, the soils of the western field would have the highest levels of arsenic. However, the highest values were found in the eastern field (E1) that has the most well-developed native plant community including mesquite, yucca, and others. It appears that arsenic levels as high as 98 ppm are not limiting to these native species. Because no food species are part of the project plantings, the effect on humans due to ingestion was not a consideration.

Table 4. Soil test results from USU Analytical Labs

Soil Tests	Analyzed Soil Samples				
	E1	C1	C2	W1	Ref (R1)
Texture	Loam	Clay Loam	Loam	Clay Loam	Sandy Loam
pH	7.89	7.86	7.90	7.87	7.81
Salinity - Ece dS/m	1.0	1.29	1.1	0.7	0.9
Phosphorous - P mg/kg	10.9	10.3	18.1	9.9	5.6
Potassium - K mg/kg	417	241	363	374	197
Nitrate-Nitrogen - N mg/kg	8.18	26.7	22.6	24.0	5.38
Zinc - An mg/kg	0.76	1.16	0.82	0.96	0.93
Iron - Fe mg/kg	3.94	5.97	6.49	4.37	4.00
Copper - Cu mg/kg	0.95	1.65	1.40	1.38	0.68
Manganese - Mn mg/kg	5.77	6.35	5.56	5.79	3.00
Sulfate-Sulfer - S mg/kg	2.1	5.5	4.8	4.3	3.1
Organic Matter %	1.7	4.7	3.2	2.6	1.2
Arsenic ppm	97.8	61.6/44.9	77.4		22.1
Interpretations	Low in Fe and S	Low in S	Low in S	Low in Fe and S	Low in Fe and S
Observations			earthworms		

SOIL MOISTURE

Hydrologic and hydraulic analyses suggest that the project areas are infrequently inundated (25- to 50-year recurrence) and the aquifer supplied by Beaver Creek is well below rooting depth in the project area. As a result, it was concluded that the majority of plantings would consist of species that are adapted to low soil moisture conditions and can be supported by precipitation. It should be noted that there are areas where more thirsty species are planted but they will be supplemented by irrigation when necessary.

Soil Moisture Probes

Soil moisture probes are used to measure soil moisture at varying depths. Four probes were installed in November 2008 with a fifth in April 2009. A final sixth probe was installed in the spring of 2011. The probes measure moisture at 6-inch increments from the soil surface to a depth of 36 inches (Figure 6). The probes provide a spot check of soil moisture data to aid in the timing and quantity of water needed for the plants.

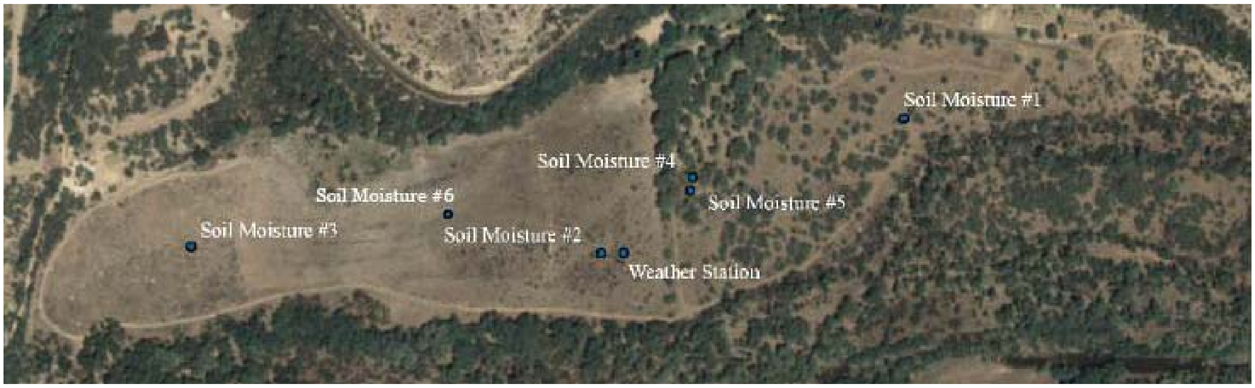

Figure 6. Soil moisture probes locations

SURFACE WATER AVAILABILITY AND DELIVERY

Plantings and existing vegetation in the project area were supported with supplemental irrigation to ensure establishment, growth and ability to compete with nonnative species. The NPS had serious concerns over the condition of the existing historical supply ditch from Montezuma Well. This ditch was surveyed for leaks, breaks and inoperable appurtenances.

The irrigation water originates from subterranean springs that naturally outflow from the well. The average flow rate is 2.2 cfs (NRCS, 1993) or about 1,000 gpm. The National Park Service has water rights for 11AF/yr (reference ID L54 (479) RNW) from this source for use within the Monument and former agricultural fields. Water is allocated to the Park through a schedule of eight days on and eight days off. Prior to the project, the NPS used the water only to irrigate the picnic area, but there is sufficient supply of water to support irrigation of the riparian restoration area.

The Well water is highly carbonated and naturally contains high levels of arsenic up to 100 parts per billion (UofA Water Resources Research Center, 2001, Vol 10 No. 2). The water has a pH of 6.4 to 6.5, alkalinity of 587 milligrams per liter (calcium carbonate), and electrical conductivity (EC) of 0.931 milliohms per centimeter (NRCS, 1993). The overall quality of water in the ditch is deemed adequate to establish and support native vegetation.

The historic irrigation system consists of “wild flooding”. With this method water is spread directly onto the fields through turnouts from the main ditch or field ditch laterals. From the well, the main irrigation ditch flows west above the flood terrace. The main ditch is in fair condition and has formed a natural travertine lining as the calcium carbonate precipitates out and minimizes seepage losses. Occasionally roots penetrate the travertine lining and seepage occurs. Most ditch leakage is the result of over topping banks and turnout disrepair and occurs primarily in the central field. The ditch length from the Well to the last turnout at the West field is approximately one mile and has a slope of approximately 0.4 percent. The picnic ground is the only area receiving irrigation water. None of the fields are presently being irrigated; most distribution laterals are in complete disrepair.

Existing Water Conveyance

A detailed inventory of existing water control structures and conveyance concerns was completed. There are ten turnout structures and four ditch riser/headgate structures along the approximate 5,000 feet of ditch from the outlet at the Well to the last turnout on NPS property. Prior to the project, the only structures in use were the six turnouts and two ditch risers surrounding the picnic area. Headgates are used to elevate the water surface and allow flows to be pushed through the turnout into lateral ditches. Only one turnout with a ditch riser existed upstream of the picnic area, near the residential area; and three turnouts (only one of which has a ditch riser associated with it) were downstream of the picnic area. Travertine deposits reduced flow at some of the ditch and turnouts and periodic cleanout is necessary. The irrigation water overtopped the ditch bank in numerous locations.

Existing Field Layout

Historically the field crops were watered using flood irrigation. Ditch turnouts delivered water to a series of lateral ditches located roughly perpendicular to the main ditch. Water was turned from the laterals to periodically flood the fields. These lateral ditches have not been used or maintained for decades and can barely be identified in the field.

PART II – PROJECT DESIGN

PLANTING DESIGN

This section describes the process used to develop the planting design for Montezuma Well Riparian Restoration Project. Based on inventory of soils and existing vegetation, the project area was divided into 6 planting areas (Figure 7). The planting design was developed using the following steps:

1. Plant communities and associated habitats based on project inventories and riparian planting zones were identified within the project area;
2. Plant communities/habitats were assigned to each project planting area;
3. A set of potential plant species adapted to those community/habitats was developed from project inventories and technical staff;
4. A planting density for woody species was identified from an unimpaired reference area upstream of the project site;
5. Existing plant densities were identified in each planting area to determine the quantity of plantings needed to meet design densities; and
6. Plantings were totaled to develop a plant/seed materials list.

Figure 7. Project planting/habitat areas

Planting Zones - Communities/Habitats

Four distinct plant communities were identified within the project area, each characteristic of desert riparian river corridors. The communities are segregated by zones defined by soil moisture, soil texture, and disturbance. These riparian planting zones generally lie as linear zones parallel to the stream channel. Some plant species may occur in more than one zone.

Riparian Habitat Area

This community is composed of "wet" riparian obligate species that are generally found in the geomorphic floodplain and low terraces. This habitat is common along Wet Beaver Creek but limited to the irrigated picnic area and immediately south of the picnic are in the project area. The area south of the picnic area (~3ac) has not received irrigation water for some time and the mature cottonwoods are showing stress and some have died and been removed. Within the project area these trees are expected to require long-term supplemental irrigation. Additional containerized trees and shrubs were planted that were composed of more xeric obligate riparian and transition species and would need irrigation only for establishment.

Buffer Strips
This community is composed of more xeric obligate riparian and transition species that are generally found on high river terraces and other areas with higher soil moistures. This habitat occurs along the interface between the lower creek bottom and the project fields and the western property boundary and the project fields. Within the project area this community would create the transition between cottonwood/willow and mesquite bosque communities and only needed irrigation only for establishment.

Mesquite Bosque Habitat
This community is composed of facultative riparian species generally found in the high terraces along desert river corridors. This habitat type is most common throughout the project area. Within the project area this community occupies the higher and drier areas of the corridor and needed irrigation only for establishment.

Grasslands Habitat
This community occurs in conjunction with the mesquite bosque community and is composed of a similar variety of annual and perennial native grass species. The open grasslands are intended to provide an additional habitat integrated with the adjacent mesquite bosque. The grasslands may require specific management (mechanical, fire) to slow the encroachment of woody shrubs. This habitat is limited to an area within the central field.
Plantings in the upper Overbank and Transition zones are expected require temporary irrigation to speed establishment. However, once root systems have been established the plant communities are expected to thrive on natural soil moisture levels driven by precipitation.

Planting Density
The ultimate planting design is intended to include diversity in vertical structure, species, and density. Dense thickets should be separated by more open, grassy areas. To identify a planting density, a reference area was identified in the unaltered transition zone/ mesquite bosque immediately upstream of the project area. The area is populated by a mature mixture of mesquite, shrubs, and grasses providing a diversity of structure, canopy, open areas, and species desired for higher quality wildlife habitat. The number of mature trees within a 1-acre plot were identified and counted on an aerial photo (Figure 8). The number of trees varied from 55 to 65 per acre. This produces a mixture of approximately 50% canopy and 50% open spaces and is roughly equal to the unaltered areas to the east of the project. A density of 65 trees per acre was selected for design purposes.

Middle story shrubs are an important component to the habitat design and are largely absent within the fallow fields of the project area. It was not possible to count individual shrubs in the unaltered area to the east from the aerial photo and the reference area in the East Field did not include the density of intermediate cover in shrubs desired in the project habitats. A density of 130 shrubs per acre was selected for design purposes which provided an approximation of the habitat structure seen in the reference area (approximately twice as many shrubs as trees).

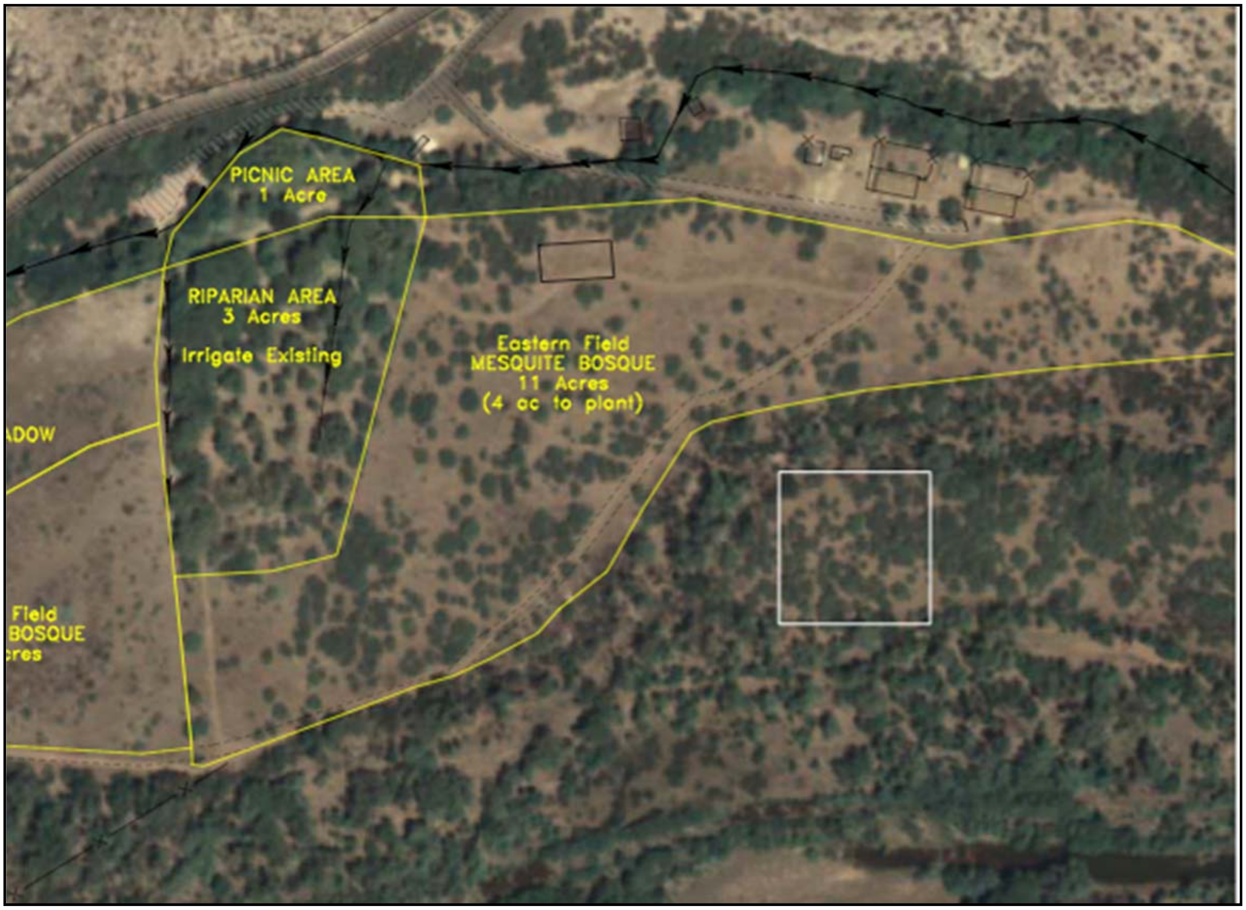

Figure 8. Reference area; transition zone/mesquite bosque

The density and distribution of woody and grass species for planting design was based on existing vegetation in the East Field and unaltered areas to the east (upstream) of the project site. A density of 65 trees and 130 shrubs per acre was selected for the planting design to provide approximately 50% canopy and 50% open space.

Planting Distribution

The trees and shrubs were planted at a density of 130 shrubs and 65 trees per acre distributed in a pattern of 6 shrubs and 3 trees per 50 ft x 40 ft planting unit. These units were planted along irrigation lines and meander back and forth to create a mosaic of vegetated and open areas (Figure 9).

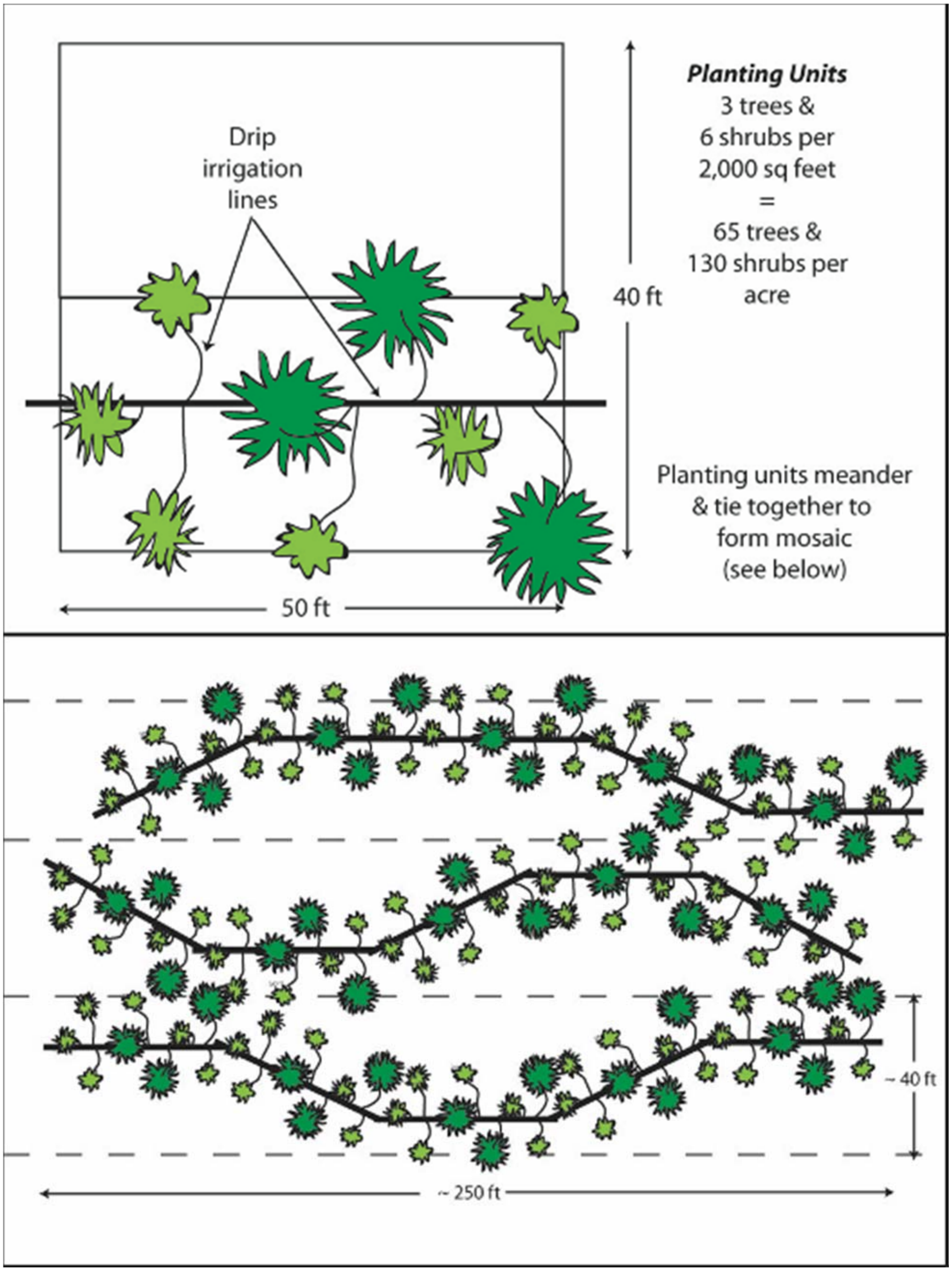

Figure 9. Tree and shrub planting design

Planting units meander to create a mosaic of vegetated and open areas.

A grasslands habitat was included in the areas between the Western and Central fields. The grasslands consist of native annual and perennial grasses native to desert riparian systems. In addition to seeding the area with native species, larger, perennial species were planted as plugs. These were to be planted in copses of 8 grass plugs to facilitate establishment. The copses are planted on a 40 ft x 40 ft grid to spread these species throughout the area (Figure 10). This planting schemes results in a density of approximately 220 grass plugs per acre or a total of 1,300 plugs.

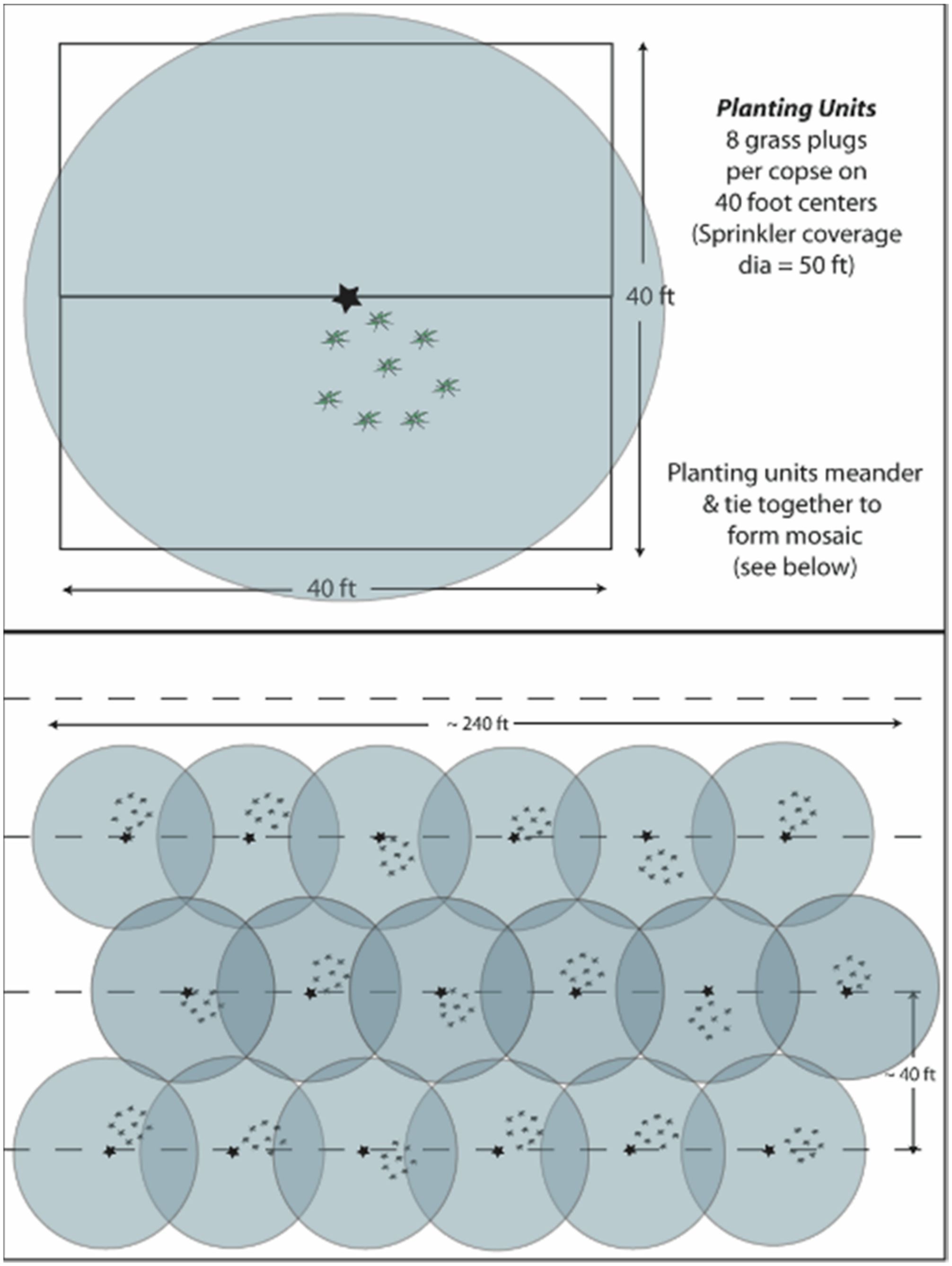

Figure 10. Grasslands planting design

Microsprinkler irrigation lines are shown as dashed lines in the bottom graphic.

Plant Materials

The number of plantings for each area was based on existing density and species distribution. For example the Eastern Field has a large number of mature mesquite so the emphasis is on the addition of shrub species. The East Field contains some shrub understory (~65%). Therefore, approximate 4 acres of the 11 acres in the East Field were planted with shrub species. The West Field, Central Field, and Riparian Area were inventoried and found to have sufficient numbers of mesquite to meet design densities. These trees are small due to the periodic mowing but are well established and are expected to prosper with supplemental irrigation. For these reasons, tree species plantings are limited to the West Buffer and South Buffer areas. The preliminary plantings by project area are presented in Table 5.

Table 5. Planting numbers by project area

	Area (acres)	Planting Design Trees	Planting Design Shrubs	# of Existing trees	# of Existing Shrubs	# of Container trees	# of Container shrubs	# of grass plugs
West Field	5.0	335	665	335	0	0	665	0
West Buffer	1.0	60	115	0	0	60	115	0
Grasslands - West	2.7	NA	NA	NA	NA	NA	NA	620
Grasslands - East	2.7	NA	NA	NA	NA	NA	NA	680
Central Field	4.5	300	535	300	0	0	535	0
South Buffer	0.5	20	40	0	0	20	40	0
Riparian Area	3.0	45	65	20	0	25	65	0
East Field	4.0	240	475	240	0	0	475	0
					Totals	105	1895	1300

Species Selection

Species selection was based on the appropriateness of the species for each habitat type. The total number of species was limited to dominant species in each area to simplify seed collection, growing, and planting. It is expected that other native species would colonize the planting areas over time. Species were selected from three sources; 1) inventories of the project site and surrounding areas (Schmidt et al 2006), 2) literature sources, and 3) experience of NPS technical specialists. Species are native to the elevation and latitude of the project site with characteristics compatible with one or more of the project habitat types. Plantings were grown in containers for 1 to 2 years. To the greatest extent possible, seeds were collected on or near the project site. Remaining seeds were purchased from reputable suppliers and certified weed free. The species and number of plantings may be modified during the project due to unavailability of seed or other factors.

The West Field, East Field, and portions of the Central Field were planted in Mesquite Bosque habitats. Riparian Buffer habitats were limited to the West Buffer along the western margin of the West Field, in the South Buffer area along the southern margin of the Central Field, and the area directly south of the riparian area. Native bunch grass was planted in the East and West Grasslands of the Central Field to supplement seeding with other native grasses. Plant species selection and numbers for each of these areas are presented in Tables 6 through 8. Some additional plantings were added to the Riparian Area south of the picnic area. No additional plantings were anticipated in the existing Cottonwood/willow habitats in the picnic area but established trees will receive supplemental irrigation.

Planting was planned to take place in the late fall or early winter, and may be split over two years to allow for seed collection and sufficient growth prior to planting. Project areas were be seeded with an appropriate native grass mix. The species and application rates are presented in Table 10. Initial plantings are schedules for fall of 2009 with a second planting in 2010. However, broad weed management must be completed prior to revegetation so that treatments will not impact plantings. The planting schedule may be adjusted depending on the effectiveness of weed management.

Table 6. Planting species and numbers; mesquite bosque habitats

Shrub Species	% of planting mix	West Field	Central Field	East Field	Total	Initial Planting	Second Planting
Atriplex canescens (four wing saltbush)	15%	100	80	71	251	X	
Baccharis pteronioides (yerba de pasmo)	5%	33	27	24	84	X	
Berberis haematocarpa (red barberry)	5%	33	27	24	84		X
Chilopsis linearis (Desert willow)	10%	67	54	48	168	X	
Encelia frutescens (Green brittlebush)	5%	33	27	24	84	X	
Ephedra nevadensis (Nevada jointfir)	5%	33	27	24	84		X
Eriogonum wrightii (Wright's Buckwheat)	5%	33	27	24	84	X	
Frangula californica (coffeeberry)	5%	33	27	24	84	X	
Lycium pallidum (pallid wolfberry)	10%	67	54	48	168		X
Purshia mexicana (Cliffrose)	5%	33	27	24	84		X
Rhus trilobata (3-leaf sumac)	5%	33	27	24	84		X
*Ribes aureum (*golden current)	5%	33	27	24	84		X
Yucca baccata (Banana yucca)	5%	33	27	24	84		X
Yucca elata (soaptree yucca)	5%	33	27	24	84	X	
Zizyphus obtusifolia (Graythorn)	10%	67	54	48	168		X
Totals	100%	665	535	475	1,675	754	838

Table 7. Planting species and numbers, Riparian Buffer habitats

Tree Species	% of planting mix	West Buffer	South Buffer	Riparian Area	Total	Initial Planting	Second Planting
Acer negundo (Arizona boxelder)	15%	9	3	4	16		X
Celtis reticulata (netleaf hackberry)	15%	9	3	4	16	X	
Chilopsis linearis (Desert willow)	16%	10	3	4	17	X	
Frangula californica (coffeeberry)	10%	6	2	3	11	X	
Fraxinus veluntina (velvet ash)	24%	14	5	6	25	X	
Jugulans major (Arizona Walnut)	10%	6	2	3	11		X
Sapindus spp. (Soapberry tree)	10%	6	2	3	11		X
Totals	100%	60	20	25	105	68	37
Shrub species							
Atriplex canescens (four wing saltbush)	20%	23	8	13	44	X	
Baccharis pteronioides (yerba de pasmo)	5%	6	2	3	11	X	
Berberis haematocarpa (Red barberry)	10%	12	4	7	22	X	
Baccharis salicifolia (Seep willow)	5%	6	2	3	11	X	
Purshia mexicana (Cliffrose)	20%	23	8	13	44		X
Rhus trilobata (3-leaf sumac)	20%	23	8	13	44		X
Ribes aureum (golden current)	10%	12	4	7	22		X
Zizyphus obtusifolia (Graythorn)	10%	12	4	7	22	X	
Totals	100%				220	143	77

Table 8. Planting species and numbers; Grassland habitats

Species	% of planting mix	Grasslands	Total	Initial Planting
Muhlenbergia rigens (Deer grass)	50%	650	650	X
Sporobolus airoides (Alkalai sacaton)	50%	650	650	X
Totals	100%	1,300	1,300	1,300

Table 9. Planting schedule

		Initial plantings (2009)		Secondary plantings (2010)	
	Total plantings	# of plantings	% of plantings	# of plantings	% of plantings
Total Containers	2,000	1016	51%	984	49%
Total grass plugs	1,300	1300	100%		

Table 10. Native grass seed mix

Mesquite Bosque - seed mix
Planting Area = 21 acres

Season	Species	Scientific Name	% of Mix	lb PLS/ac for Pure Stand	lb PLS for 21 acres*1
cool season	'Arriba' Western Wheatgrass	(Pascopyrum smithii)	20%	9	75.6
warm season	Sideoats Grama	(Bouteloua curtipendula)	20%	8	67.2
warm season	Plains bristlegrass	(Setaria macrostachya)	30%	4	50.4
cool/warm season	Sand Dropseed	(Sporobolus cryptandrus)	30%	0.5	6.3
	TOTAL		100%		199.5 lbs bulk (9.5 lbs/ac)

*1 Planting to be done by drill seeding, values have been increase by a factor of 2.

Grassland Meadow - seed mix
Planting Area = 6 acres

Season	Species	Scientific Name	% of Mix	lb PLS/ac for Pure Stand	lb PLS for 6 acres*2
cool season	'Arriba' Western Wheatgrass	(Pascopyrum smithii)	15%	9	32.4
warm season	Sideoats Grama	(Bouteloua curtipendula)	25%	8	48.0
warm season	Green Sprangletop	(Leptochloa dubia)	25%	2	12.0
warm season	'Salado' Alkali sacaton	(Sporobolus airoides)	10%	1	2.4
cool/warm season	Sand Dropseed	(Sporobolus cryptandrus)	20%	0.5	2.4
warm season	'Grant' Cane Beardgrass	(Bothriochloa barbinodis)	5%	1.5	1.8
	TOTAL		100%		99.0 lbs bulk (16.5 lbs/ac)

*2 Planting to be done by drill seeding, values have been increase by a factor of 4.

IRRIGATION WATER MANAGEMENT

Native plant communities can be restored along high stream terraces and retired agricultural fields. However, depending on the available soil moisture, newly planted vegetation may require supplemental irrigation after planting and during several growing seasons for successful root establishment. An irrigation system adapted for site conditions (soil, water, plants grown, climate, etc.) must be available and capable of applying water to meet the restoration purposes. Suitable irrigation methods include surface (Border, Corrugation, and Furrow) or micro-irrigation (drip or sprinkler).

Soil-Plant-Water Relationships

Basic understanding of soil-plant-water relationships is essential to plant establishment and root development. Plant response to irrigation is influenced by soil characteristics. How a plant root system grows and uses available moisture and nutrients depend on soil texture, depth, organic matter, drainage, topography, fertility, and chemical characteristics. In planning and operating an efficient irrigation system, the primary concerns are:

- the available water;
- the field characteristics (slope, width of field, length of run, water delivery, field layout);
- the irrigation method;
- the water-holding capacity of the soil (particularly in the root zone of the plant);
- the water-intake rate of the soil;
- the root system of the plant to be grown;
- the amount of water that the plant uses;
- and the necessary irrigation schedule

Irrigation Methods

Irrigation methods suitable for establishment of native plant communities at the project site include surface systems (Border, Furrow), sprinkler or drip irrigation. Surface irrigation methods use simple equipment and have low initial cost; however they require larger amounts of water to obtain efficient application. Sprinkler and drip irrigation methods deliver light, frequent applications of water that wet a specific section of the soil. Natural conditions such as soil type, slope, water availability and requirements, consumptive use, and frequency of irrigation impact the choice of irrigation methods and need to be adjusted based on the method used.

Based on an evaluation of initial cost, operation cost, and water efficiency, combination drip/sprinkler irrigation was designed. Drip irrigation was selected to minimize use of a limited water right and target desired plants without increasing soil moistures for non-native competitors. Specific planting areas are targeted to receive surface irrigation as needed from existing and repaired turnouts on the ditch. See irrigation system design section.

Irrigation Requirements

Several characteristics of the soil and plants are essential to developing an irrigation management strategy (NRCS 1997).

Field Capacity (FC): A soil is at field capacity if it is holding all the moisture it can when it is free to drain. This is the upper limit of storable water in the soil once free drainage has occurred after irrigation.

Permanent Wilting Point (PWP): A soil is at the wilting point when plants have removed all the moisture they can at which a plant wilts so much that it does not recover.

Available Water Capacity (AWC): The capacity of soil to hold water available that can be absorbed by plant roots (Figure 11). It is the water held between field capacity and permanent wilting point. This value, along with plant consumptive use, helps determine when to irrigate. It is calculated by multiplying the soil depth in inches by the AWC in inch per inch.

Soil Intake Rate: The average rate of water entering the soil under irrigation, usually expressed in inches per hour. The intake family number of a soil relates the time required to infiltrate a given quantity of water in a specific soil type. Since the intake rate of the soil decreases as more water is applied, the family designations (e.g., 0.1, 0.5, 1.0, etc.) reflect the final intake rate of the soil. This is relatively low at the project site (0.3 to 0.6) due to the soil texture (silty loam to silty clay loam), Table 11. Soil intake characteristics directly influence length of run, required inflow rate, and time of set that provide a uniform and efficient irrigation without excessive deep percolation and runoff.

Table 11. Available water capacity at given field locations.

Field Location	Soil Texture	AWC Average (in./in.)	AWC Average (in./ft)	Border Intake Family	Furrow Intake Family
Eastern Field	Silty Loam	0.12 - 0.21	2.2	0.4	0.5
Central Fields	Silty Loam	0.12 - 0.21	2.2	0.3	0.3
Western Fields	Loam	0.08 - 0.21	1.9	0.5	0.5
Picnic Area & Riparian Buffer	Silty Loam	0.12 - 0.21	2.2	0.3	0.3

Management Allowable Depletion (MAD): This is the percentage of the available soil water that can be depleted between irrigations without serious plant moisture stress. Different plants require different soil-water depletion levels at different stages of growth. MAD values during the growing season are typically 30 to 50 percent for shallow rooted plants and 50 to 65 for deep-rooted plants. The planned MAD rate used was 50% of available water-holding capacity in the upper half of the root zone where the majority of root water extraction occurs.

Effective Rooting Depth of Plant: The root zone depth of a plant is the part of the soil that can be penetrated by plant roots. See Figure 11 for typical water extraction in the root zone. By managing soil water replacement at the primary extraction depths as shown in Table 12 optimum growth can be achieved. Rooting depths are greater on sandy soils than on clay soils. With uniform deep soil, about 70 to 80 percent of soil moisture withdrawal by plant roots is in the upper half of the rooting depth.

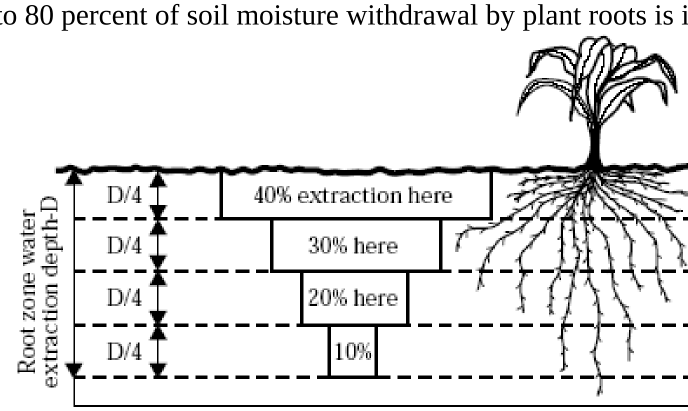

Figure 11. Typical water extraction in a root zone.

Plants use water rapidly from the upper part of the root zone and more slowly from the lower parts. About 70 percent of available soil water comes from the upper half of a uniform soil profile (USDA-NRCS, 1997)

Table 12. Managing soil water replacement in primary extraction depth.

To prevent permanent wilting of plants, the soil moisture level should never reach less than fifty percent of capacity (about 2 inches of soil moisture depletion for the Mesquite-Bosque and 1 inch of soil moisture for the grassland meadow.)

Field Location	Soil Texture	AWC Average (in./in.)	AWC Average (in./ft)
Eastern Field	Silty Loam	0.12 - 0.21	2.2
Central Fields	Silty Loam	0.12 - 0.21	2.2
Western Fields	Loam	0.08 - 0.21	1.9
Picnic Area & Riparian Buffer	Silty Loam	0.12 - 0.21	2.2

<u>Plant Consumptive Use (CU)</u>: The amount of water a plant uses, also called water demand. This varies by climatic areas. In arid areas, plants require more water than in humid areas because of greater evaporation and transpiration losses (ET). There is limited information for consumptive use of native plants.

Initial Irrigation Schedule

Recommended water replacement needs for establishment of trees and shrubs is 8 gallons/week. Planned water needs for the grassland meadow is 120 gallons/week (gross application of 0.25 inches).

IRRIGATION SYSTEM DESIGN

Both surface irrigation and micro-irrigation methods were evaluated. Surface irrigation generally has less initial cost to repair infrastructure. However, the systems have higher operation costs due to the need for constant repair and maintenance. In addition, these methods spread water more widely requiring greater amounts of water and potentially supporting competing invasive species. The pressurized systems require greater capital costs but can deliver water more efficiently and require less attention to operate.

After a careful evaluation of all methods it was decided to utilize a combination drip and sprinkler system to supply water to the new project plantings and to repair the ditch and selected turnouts to enhance and improve the surface irrigation around the picnic and riparian buffer areas. This combination would allow effective temporary irrigation for the establishment of project plantings by using the ditch to deliver water to the drip and sprinkler systems and improve the long-term irrigation needs for the established riparian vegetation around the picnic and riparian area.

Project areas were irrigated as follows:
<u>Grassland Meadow Area</u>: Sprinkler irrigation
Mesquite-Bosque Areas: Drip irrigation
<u>Buffer Strips</u>: Drip irrigation (with future surface lateral along West strip)
<u>Picnic Area</u>: Continued surface irrigation
<u>Riparian Buffer Area</u>: Drip irrigation and surface application via ditch laterals

The irrigation system design components consist of the following:

1. Replace and renovate existing water control structures
2. Improve ditch conveyance in the main ditch and ditch laterals
3. Prepare the fields for planting and irrigation
4. Install temporary micro-irrigation system (pressurized pipeline)

The following describes the irrigation system design components in more detail:

Water Control Structures
The work consisted of furnishing and placing materials needed to replace two water control structures (one near the picnic area, TO4, and the downstream turnout, TO1); and renovating other structures along the main ditch. It is not recommended that any of the existing structures be removed as the Park may choose to use them in the future. Any use of the irrigation water was within the NPS water rights.

The two water control structures that are being replaced include the turnout near the picnic ground and the last turnout before the main irrigation ditch leaves the Park property. TO4 can supply surface water through the renovated lateral ditch to the Riparian Area, can supply a small stream of surface water to the future interpretive plots, and may also supplement the grasslands using gated pipe at a future time. TO1 can supply surface water to the West buffer strip through the renovated ditch lateral along the west boundary.

The two water control structures that are recommended for renovation are TO2 and TO3. The primary renovation work was to stop the leaking and to add compacted fill in low spots near the structures to prevent water from overtopping the ditch bank. The Park may choose to turn small amounts of water to the base of the hillside for watering of existing seep willow community (TO2) and supplement the grassland meadow (TO3).

Ditch Conveyance
The work shall consist of furnishing and placing materials needed to repair/renovate the main irrigation ditch and laterals, placing fill along ditch banks in overflow locations, and all appurtenances needed for improved operation.

The main ditch from the Well crosses under a NPS service road in a 105 ft length 24-in. culvert; the capacity is slightly reduced due to calcium carbonate buildup. Even with the reduction it adequately conveys the Well discharge. Due to budget constraints, no immediate action is anticipated. However the culvert condition will continue to be observed and, if funds are available, may be replaced with 40-foot 18-inch diameter HDPE pipe under roadway following AWPF approval (this was never needed during the grant period).

Field Preparation
Effective management of invasive weed species and a good seed and planting bed, free of debris such as rocks, clods, and crusty topsoil must be in place prior to planting. A good planting bed should be firm but pliable enough to push a tilling spade 18 inches into the soil.

Due to the agricultural history of the project area and high calcium carbonate levels of the irrigation water a good planting bed may require minor mechanical field preparation including site specific tilling.

Pressurized Irrigation Pipeline System

The work consisted of installing a temporary micro-irrigation system. The micro-irrigation system includes three portable pumps, main lines, distribution manifolds, lateral lines, and all other appurtenances for operation.

The drip system is used to irrigate the tree and shrub container plantings in the mesquite bosque, riparian buffer, and riparian areas. Each planting receives a volume of 2 gallons per hour (gph) through 2 separate 1-gph emitters. The use of two emitters for each plant ensures a flow of water in the event one is clogged. The emitters are be fed from ¼-inch poly pipes in turn supplied by larger poly pipes. Plantings in the grasslands are more widely scattered and require a broader application of water. A series of micro-sprinklers with a spray diameter of ~ 50 feet and flow rate of 30-gpm irrigate the grassland areas to the west of the picnic area. The sprinklers are set at 40-foot spacing to allow overlap. See Figure 9 and Figure 10 for a schematic.

The irrigation system is pressurized by gasoline powered portable pumps at three separate stations along the ditch. Water was taken directly from the ditch and pumped to field irrigation systems through PVC or polyethylene pipe (PE). Larger diameter PVC pipes are buried for protection from ultra violet radiation. The majority of the pipe is PE and distributed on the surface reducing cost and disturbance. Each pump serviced two irrigation areas to optimize management flexibility. The irrigation system is designed to be temporary for the establishment of the plantings and removed when that has been accomplished. Should it be required, individual pieces of the system can be left in place or modified to provide longer-term irrigation.

Water Budget and Initial Irrigation Schedule

Based on the evaluation of climate and water needs in the previous section, irrigation is likely to be required for four months within the period between April 1 and October 1 depending on the annual variations in precipitation. The initial irrigation management strategy consisted of 4-hour irrigation periods on a weekly schedule. Each pump station supplied water to two areas or “sets” weekly allowing the irrigation to take place in a single day. This schedule provided 8 gallons of water to each container planting, 16 gallons to each established tree in the riparian area, and approximately ¼-inch of water throughout the grassland areas.

The system was maintained during each irrigation period. All emitters, micro-sprinklers, and pipes were visually inspected for clogging, leaks, or insufficient flow. Soil moisture and plant condition were monitored during this period and the irrigation schedule adjusted accordingly.

Based on a 4-month schedule (16 weekly periods) a little more than 2 acre-feet of water was required annually for the project (

Table 13). This is well within the 11 acre-foot NPS water right (Maricopa County 1985). In addition, maximum irrigation demands are approximately 85 gpm, well below the 1,000 gpm available from the ditch.

Table 13. Annual irrigation water budget

Field	Area (acres)	Flow Rate (gpm)	Irrigation time (hrs)	Volume/set (gallons)	# of sets/year *	Total Annual Volume (acre-ft/yr)
West Field/buffer	5.0	23.2	4	5,572	16	0.27
Grasslands-west	2.7	39.2	4	9,403	16	0.46
Grasslands-east	2.7	42.6	4	10,217	16	0.50
Central Field/buffer	5.0	33.7	4	8,094	16	0.40
Riparian Area	3.0	17.2	4	4,129	16	0.20
East Field	4.0	19.0	4	4,556	16	0.22
Total Area (acres)	22.4		Annual Irrigation volume (acre-ft)			2.06

* Assume watering once a week for 4 months; 16 periods annually

WILDLIFE HABITAT IMPROVEMENTS

Wildlife Habitat Improvements consisting of brush piles, raptor perches, and/or bat houses were included in the design to enhance natural habitats. Initial implementation included 4 brush piles, 2 raptor perches, and 2 bat houses. The use of these structures were to be evaluated through project monitoring. Additional structures will be constructed as use patterns and optimal locations are identified through monitoring. The exact location for these structures were identified in the field during initial construction and located on the final As-built drawings.

Brush Pile

A brush pile is a mound of woody vegetative material to furnish additional wildlife cover. Loosely formed brush piles can provide nesting habitat, resting areas, concealment, and protection from predators. Brush piles are placed along field edges.

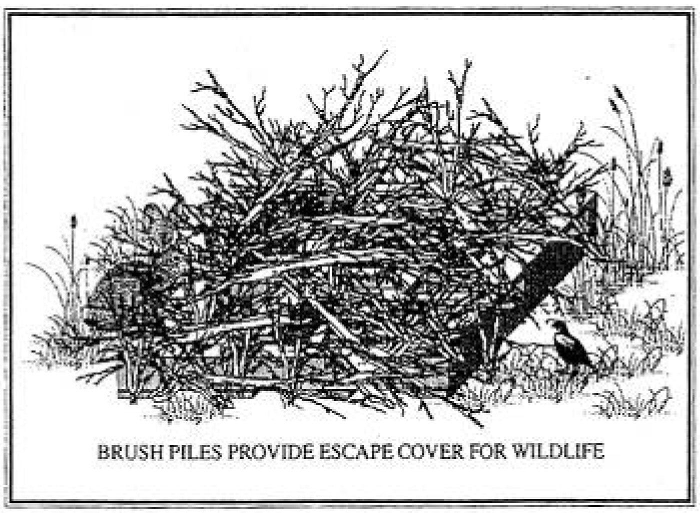

Figure 12. Brush pile

Raptor Perch Structure

Raptor perches provide strategically-located vantage points to help improve hunting efficiency. Installation of raptor perch poles of varying heights provide a natural control of small mammals, resulting in a reduction of damaged plants and temporary micro-irrigation pipeline. An added benefit is the increased bird-watching enjoyment from the Park visitors. Perches can be installed in existing trees or artificial poles along field edges. The height above ground should range from 8 to 20 feet.

All perches should be placed with the horizontal axis pointing east-west to avoid instability due to wind direction and changing visibility due to sun and moonlight.

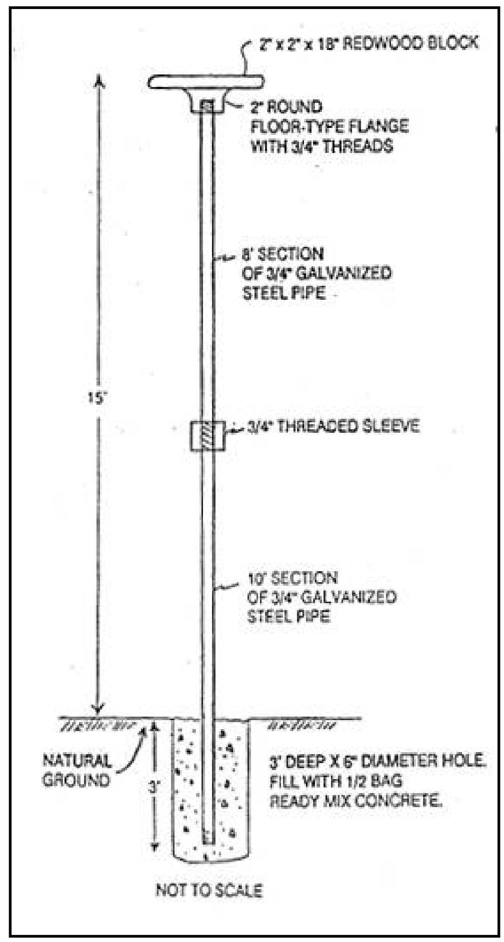

Figure 13. Raptor perch

Bat House

Bats are important in pollination, seed dispersal, and insect control. The key to conducting a successful bat house program is to provide the appropriate internal bat house temperatures desired by bats for their various roosting needs. This is often accomplished by placing at least two houses on the same building or within the same general vicinity (known as pairing) so that bats can move from house to house at different times of the season to take advantage of optimum temperature levels. It is best to start with one pairing of bat houses, expanding in numbers only after a few have attracted bats. Those that fail to attract bats within two seasons of being erected may not be achieving suitable temperatures. Moving, recaulking, or repainting these boxes may be necessary to attract bats. Annual cleaning and maintenance is required, as with bird houses. Bat houses can be constructed of most types of wood except pressure-treated wood. Houses can be placed on poles, sides of buildings, dead trees receiving ample sunlight, or other structures. They should be placed so that the bottom of the house is 12 to 15 feet above ground in order to provide adequate flight path and discourage predators.

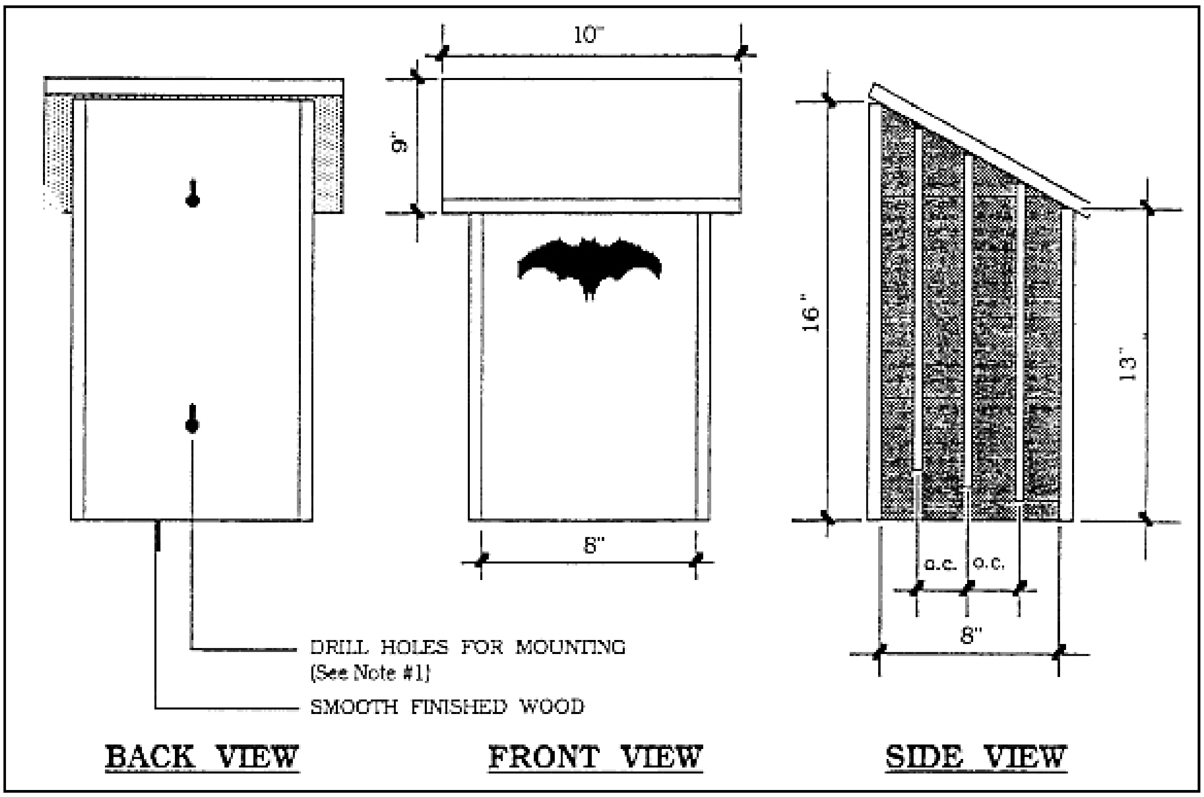

Figure 14. Bat house details

PART III: CONSTRUCTION AND IMPLEMENTATION

In the following section, a task by task assessment of the project implementation is presented. Weed management, irrigation installation and planting occurred in phases over multiple years. A narrative of activities for each task in each year is provided.

TASK 4 – WEED MANAGEMENT

Weed management within the project area was designed to follow the management strategies developed by the Park Service and outlined in their Invasive Plant Management Plan and EA for Montezuma Castle and Tuzigoot National Monuments (NPS August 2007). At the beginning of the project, an inventory of the project area was conducted and a list of invasive species was compiled (Table 14). From this list, the species that were most problematic and aggressively targeted during treatments were Russian thistle, Silverleaf nightshade, bull thistle, Maltese star thistle and the Johnsongrass.

Table 14. Invasive Species

Scientific Name	Common Name	Code	Duration
Forb Species			
Centaurea melitensis	Maltese star-thistle	CEME	Annual
Chorispora tenella	Blue mustard	CHTE	Annual
Cirsium vulgare	Bull thistle	CIVU	Biennial
Convolvulus arvensis	Field bindweed	COAR	Perennial
Descurainia sophia	Flixweed	DESO	Annual
Marrubium vulgare	Common horehound	MAVU	Perennial
Plantago lanceolata	European plantain	PLLA	Annual/Biennial/Perennial
Salsola tragus	Russian thistle	SATR	Annual
Solanum elaeagnifolium	Silverleaf nightshade	SOEL	Perennial
Verbascum thapsus	Common mullein	VETH	Biennial
Grass Species			
Aegilops cylindrica	Jointed goatgrass	AECY	Annual
Bromus diandrus	Ripgut brome	BRDI	Annual
Bromus inermis	Smooth brome	BRIN	Perennial
Bromus rubens	Red brome	BRRU	Annual
Cynodon dactylon	Bermuda grass	CYDA	Perennial
Festuca arundinacea	Tall fescue	FEAR	Perennial
Paspalum dilatatum	Dallis grass	PADI	Perennial
Sorghum halepense	Johnsongrass	SOHA	Perennial

Weed management activities during the project period were comprised of mowing and herbicide application. The purpose of mowing was to reduce biomass of growing weeds and to eliminate flowering heads before they could set seed. The mowing also allowed for efficient application of herbicide by opening up thick ground cover and exposing growing weeds.

Two types of herbicide were applied during the duration of the project. The first was Roundup Pro Concentrate™ which utilizes glyphosate as the active ingredient. This is an amino acid inhibitor used to control annual and perennial grasses and broadleaf plants. It is a broad-spectrum, non-selective systemic herbicide that is absorbed on contact by the plant. It is rapidly deactivated in the soil. It was applied at a 2% mixture at a rate of approximately 25 gal/acre. A blue colorant (Hi-Light™) was used to mark sprayed areas and avoid over application.

The other type of herbicide was Milestone™ which is an *Aminopyralid* herbicide. This is an auxin-like growth regulator (selective homone-based) used to control annual and perennial broadleaf plants in grass crop situations. It has low soil mobility with a half-life in the soil of 35 days. This herbicide is mixed with a methylated seed oil (MSO) surfactant along with the blue colorant. It was used throughout the site in areas where abundant native grasses occurred. This herbicide was potentially harmful to mesquite and great care was taken to not expose existing trees. Consequently all Milestone applications were made with a hand operated spot sprayer. Milestone was applied in a 0.006% solution at a rate of 60 gal/ac or 6 oz Milestone per acre.

The herbicide was applied with backpack sprayers for individual spot spraying with Milestone, or with a boom sprayer attached to an ATV or UTV (Figure 15) when broadcast application with Roundup was warranted.

Figure 15. ATV mounted boom sprayer.

ATV use in National Parks was ended after the first year of the grant as part of a nationwide safety effort. UTV mounted sprayers were utilized for the remainder of the project.

Typically two weed management efforts have been conducted annually. An early spring broadcast application of the Roundup herbicide was used to target emerging *Salsola spp.,* and *Solanum* plants. Spot spraying with Milestone targeted *Marrubium*, and *Centaurea* plants. In the Riparian Buffer Zone next to the picnic area, dense areas of Johnson grass were also targeted with Roundup.

Later in the summer and early fall during monsoon season, a second herbicide application was typically conducted. Species targeted during this period were *Solanun, Marribium* and *Centaurea* plants. In addition, areas with Johnson grass and bermuda grass were also treated. Mowing activities during the late summer targeted *Salsola* plants which survived the spring spraying.

Weed management activities associated with this project were initiated during the fall of 2008. Natural Channel Design and National Park Service personnel conducted mowing and herbicide application. Applications were made under the direction of Dennis Casper, a National Park employee and licensed herbicide applicator. Spring and late summer/early fall treatments were conducted annually throughout the project time period, the last occurring during the summer of 2013. As the project progressed and native vegetation took hold and irrigation lines were laid down, mowing and boom spraying with wide spectrum herbicide was reduced. Mowing was restricted to areas without irrigation lines and was replaced by selective mechanical removal. As grasses took hold in specific areas boom spraying with wide spectrum herbicides was replaced with spot spraying and broadleaf only herbicide applications.

During the 2011 season, more effort was made in the mechanical control of weeds. Mechanical weed treatment involved using a gas powered weed trimmer, a mower, as well as rakes, hoes, and scythes to chop down Russian thistle, bull thistle, and annual sunflower some of which were over six feet tall. These annual plants are effectively controlled by mechanical removal before they go to seed. Some hand-pulling of Maltese starthistle, Russian thistle, and bull thistle was performed by NCD personnel and NPS with the volunteer help of American Conservation Experience (ACE), Coconino Rural Environmental Corps (CREC), Camp Verde High School students, and other volunteers. See Figure 16 for areas where mechanical weed treatment was performed.

Invasive weeds were often benefiting from irrigation and became quite vigorous in the vicinity of the caged plants. In order to prevent over-shading and competition for available nutrients, the invasive weeds needed to be removed. This was an ongoing process throughout the growing season. Whenever time was available during operation of the irrigation system, weeds were pulled and/or dug out. About 25% of the time reported operating the irrigation system was spent weeding manually.

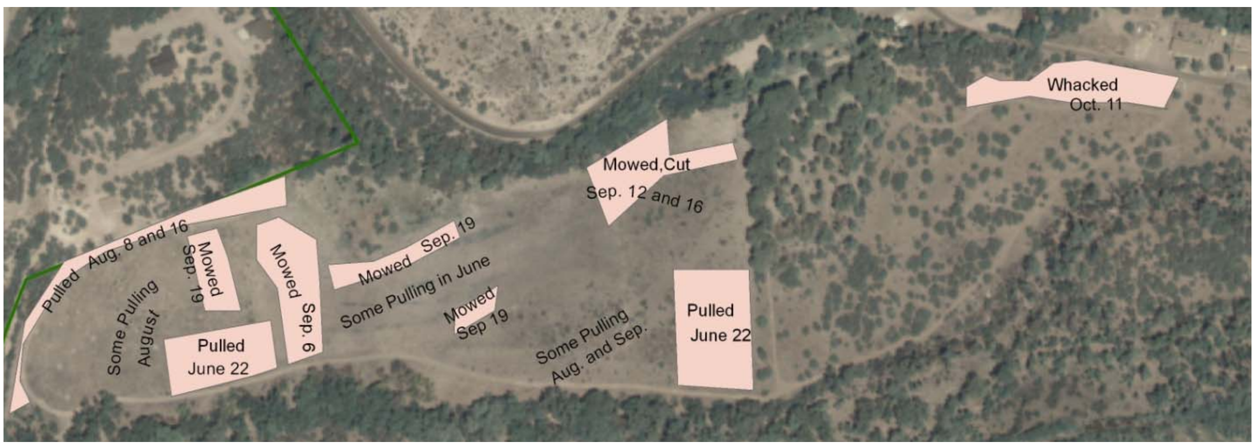

Figure 16. Mechanical Weed Treatment Areas

The efficacy of the weed treatments has had mixed results. Silverleaf nightshade and horehound remain as problematic perennials. Treatment of these plants has decreased their density somewhat and kept their distribution from increasing. These plants have not responded to herbicide as well as other plants do. It could be that a different method of applying the herbicide should be used instead of straight down, such as spraying from all sides. It may be that these plants must be removed mechanically instead of chemically. It is clear from monitoring efforts that further weed treatments need to be done.

In 2012, an additional herbicide, Escort XP™ , was added at the project site. This non-selective herbicide was used on horehound throughout the project site. Past applications of Roundup and Milestone prove less than adequate to control this invasive species. A total of 9 gallons of a 0.03% mix of Escort XP was applied by wand attachment to the UTV mounted tank sprayers to individual horehound plants.

As reported in 2011, Silverleaf nightshade and horehound continues to be problematic species. Johnsongrass and dallisgrass have increased slightly in the West and Central fields due to availability of water. Russian thistle, however, has responded well to treatment and has declined in both extent and degree of infestation. Good results were experienced in controlling horehound on the project due to the use of Escort XP as well as increased effort in targeting this species. There was one area at the terminus of the pollinator garden ditch where enhanced flood irrigation caused a horehound germination event in a previously heavily infested site. Further weed management activities were needed to ensure that declining populations continue to decline and to focus efforts on species that continue to be problematic.

Work on non-native and invasive weed management in 2013 involved both mechanical (mowing, hand pulling and weed whacking) and chemical (herbicide spot spray) treatments. Non-native and invasive species targeted in 2013 included: Russian thistle (*Salsola tragus*), Johnsongrass (*Sorghum halepense*), jointed goatgrass (*Aegilops cylindrical*), puncturevine (*Tribulus terrestris*), and blue mustard (*Chorispora tenella*). The work was conducted between April and September 2013 by National Park Service (NPS) personnel and volunteers (CREC- YCC). Natural Channel Design, Inc. made several trips to the site to coordinate with NPS and to observe site conditions.

TASK 5 - IRRIGATION WATER MANAGEMENT

See Appendix B for As-Built Construction Sheets.

The construction, maintenance and operation of the irrigation system was an ongoing process for this project. Construction efforts started in 2009 with the maintenance of the main ditch and installation of new water control turnout boxes (Figure 17).

Figure 17. Site map with irrigation activities in 2009.

Ditch repairs included raising and reinforcing the ditch berm where water had eroded the surface whenever the ditch became blocked and water overflowed. Maintenance also included clearing out lateral ditches in the picnic area. In addition to the ditch work, two water control structures were replaced at turnouts number 1 and 4 (Figure 17 and 18).

Figure 18. Installing turnout structure #4.

2009 also saw the installation of the drip irrigation in the riparian buffer zone, which fed off pumping station number 3 (Figure 19). A gas powered pump was installed at station 3 and a one-inch polyethylene (PE) irrigation main line was routed adjacent to the riparian buffer zone. ½ inch PE laterals fed off the main line through the targeted zone and ¼ inch drip lines with 1 gallon/hour emitters were strung out to irrigate a total of 68 trees in this zone.

Figure 19. Pump and irrigation lines

The 2010 season saw the installation of the remainder of the micro-irrigation system including the grassland meadow micro-sprinkler system (Figure 20). Lateral ditches were also improved throughout the riparian area and western buffer.

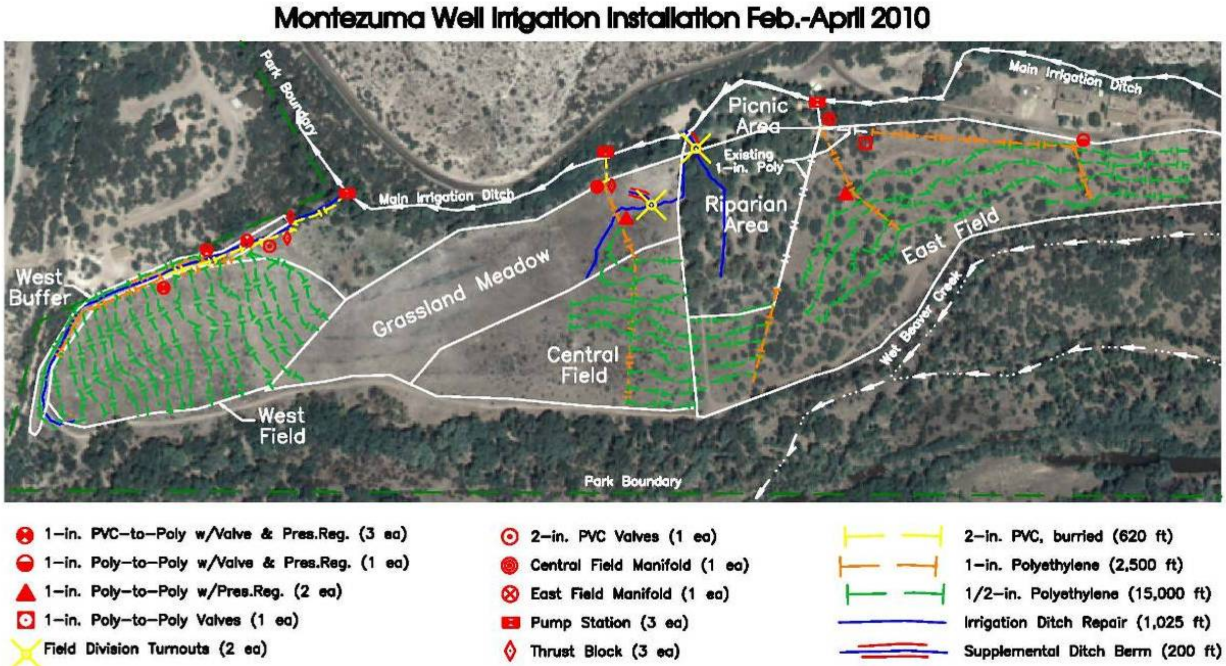

Figure 20. Irrigation improvements, aerial view

A mini-excavator was used for clearing debris and renovating the ditch laterals. Ditches were cleaned along historical irrigation ditch routes to approximately 6 inches below existing depth (Figure 21). These ditches were used to flood irrigate the riparian area adjacent to the picnic area and the butterfly garden area.

Figure 21. Irrigation lateral ditch excavation

Temporary Drip Irrigation Installation-2010

The temporary drip irrigation system consists of buried 2-inch PVC pipe, junction boxes, one-inch, ½-inch and ¼-inch polyethylene tubing (on surface); and installation of appropriate fittings at line junctions and plant sites (Figure 22 and Figure 23). Each field was subdivided into separate zones or groupings of drip emitters that could be operated independently. This was done to ensure that an adequate volume and pressure of water was available to the plants. Each pump operated two to four different zones.

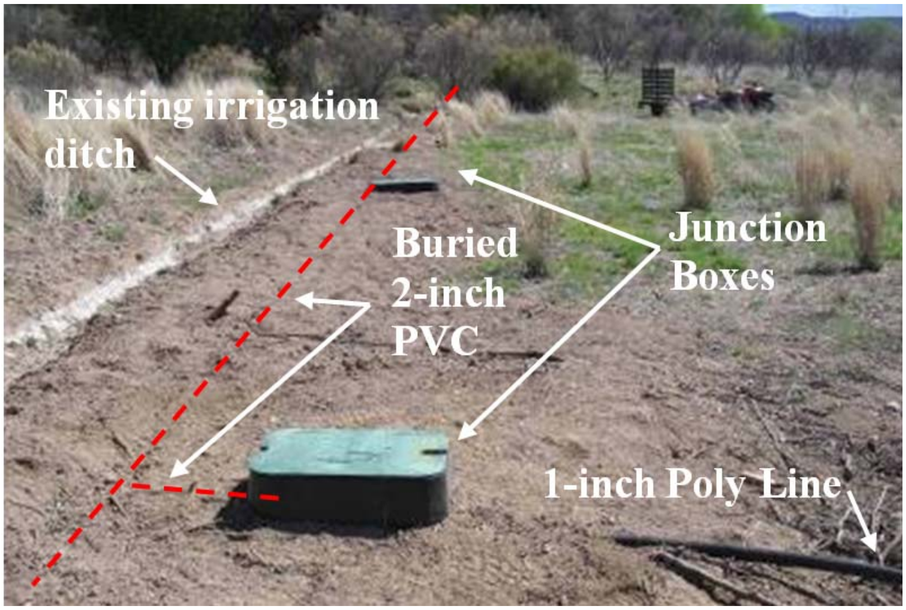

Figure 22. Typical irrigation layout

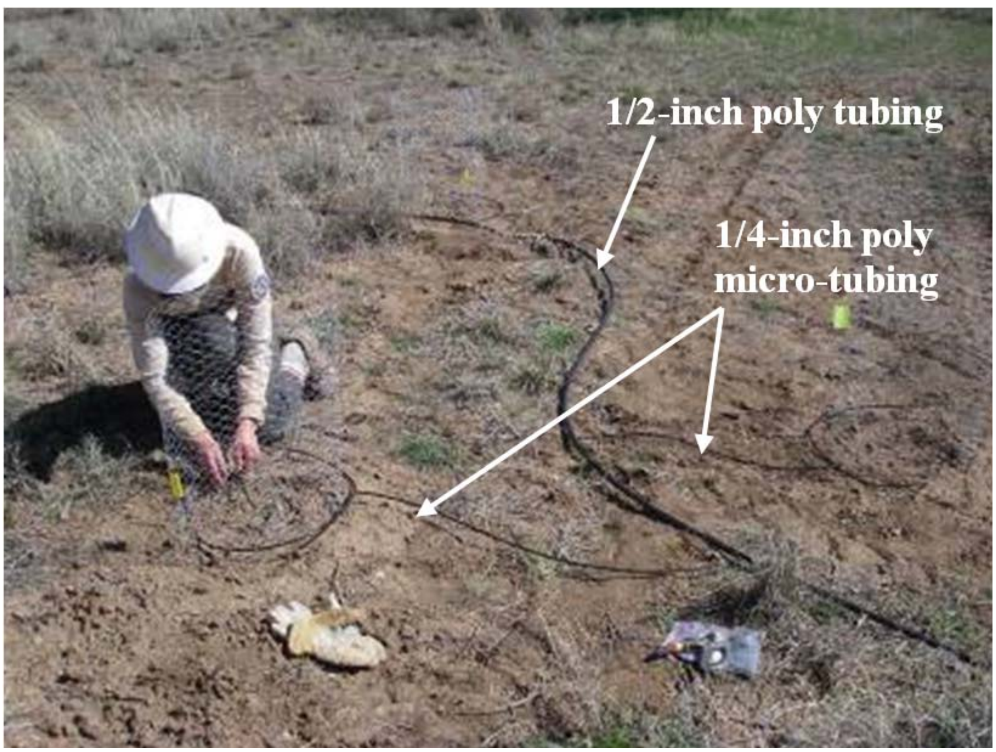

Figure 23. Running drip lines to plants.

The following list summarizes the materials installed for the micro-irrigation system.

• Irrigation Ditch Lateral Repaired	1,025 linear feet
• Supplemental Irrigation Ditch Berm Material	200 linear feet / ~7.5 cubic yards
• Field Division Turnouts Installed	2 each
• 2-inch PVC Pipe, Buried	620 linear feet
• Thrust Blocks Installed	3 each
• Junction Boxes Installed	10 each
• 1-inch Polyethylene Tubing Installed	2,500 linear feet
• ½-inch Polyethylene Tubing Installed	15,000 linear feet
• ¼-inch Polyethylene Micro-tubing Installed	7,500 linear feet
• Junctions and End Caps for ½-inch Tubing	56 each
• Couplers and Tees for ¼-inch Tubing	832 each
• Drip Emitters Installed	1,664 each
• Pump Station Manifolds Constructed	2 each

Within the grassland areas, a micro-sprinkler system was installed. The sprinkler system is fed by a gas powered pump through 1-inch PE pipe. Lateral lines consisting of ½ inch PE were routed throughout the grasslands and the micro-sprinklers were attached with ¼ inch lines (Figure 24).

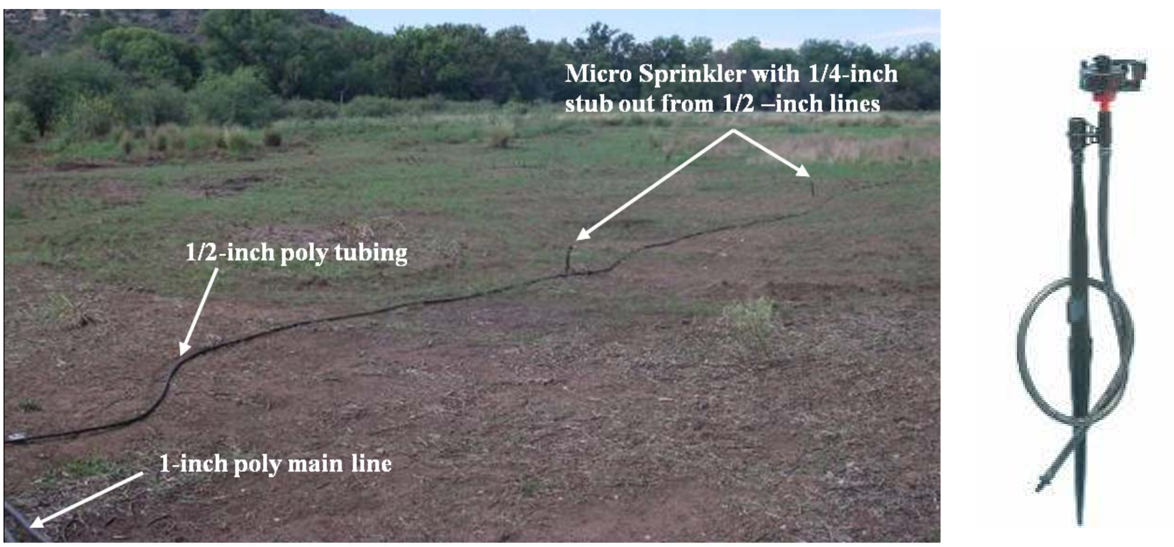

Figure 24. Sprinkler line layout with photo of sprinkler

The following list summarizes the materials used for the installation of the sprinkler system.

• Buried 2-inch PVC main delivery line	535 linear feet
• Overland 1-inch PE secondary delivery line	700 linear feet
• ½-inch lateral PE lines	5740 linear feet
• 360º anti-insect micro-sprinkler	174 each
• Thrust blocks	2 each
• 2x1x2-inch PVC tees	3 each
• 1-to-1/2-inch tees	33 each
• 1-in. swivel tees	2 each
• Junction boxes	3 each
• 1-inch ball valve	4 each
• 1-inch pressure regulator	4 each

During May through October 2010, the irrigation system was operated 14 separate times. There were a total of three pumping stations. Each pumping station fed two to four drip or sprinkler zones. At any one time, each pump would feed one to two zones, depending on the number of emitters or sprinklers attached. Each zone required four hours of operation.

Irrigation Set No. 1 (Pumping Station No. 1): two drip zones and one sprinkler zone
Irrigation Set No. 2 (Pumping Station No. 2): One drip zone and one sprinkler zone
Irrigation Set No. 3 (Pumping Station No. 3): Four drip zones.

Drip and Sprinkler Installation in 2011

2011 saw the completion of the drip irrigation system with the final installation in the southwestern part of the central field, which was planted this spring (Figure 25).

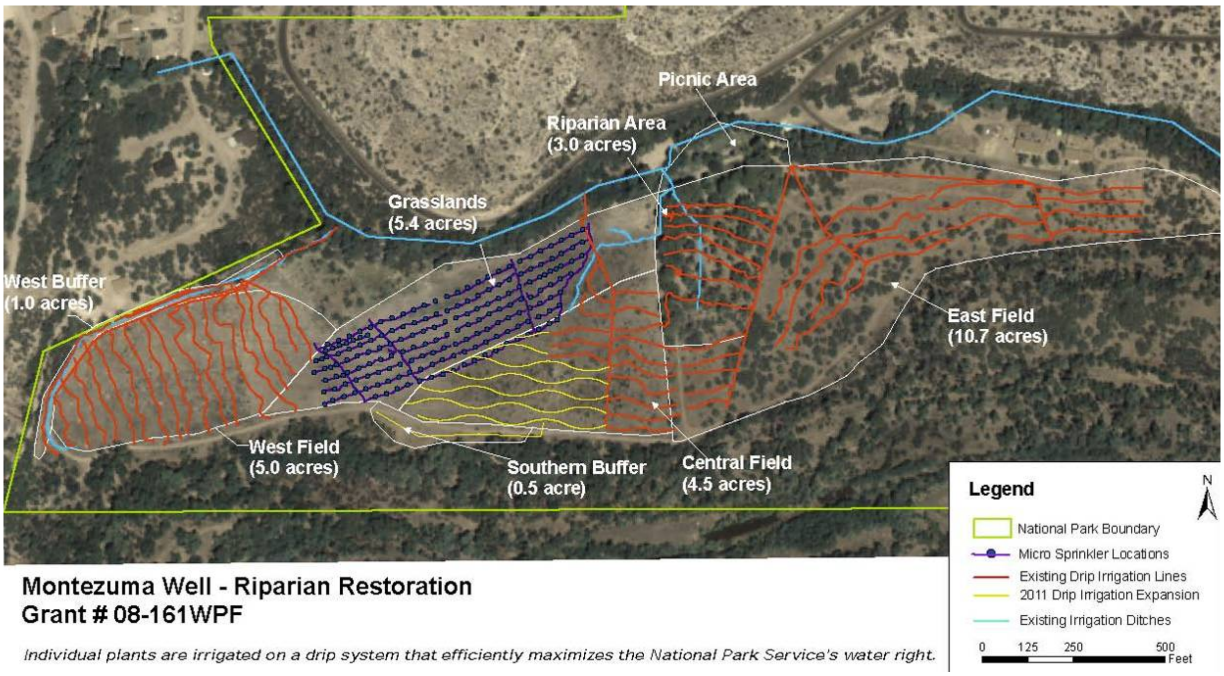

Figure 25. Final irrigation layout

Installation involved laying out 1-inch polyethylene (PE) pipe overland from an existing junction and splicing in ½-inch lateral lines. Two, 1 gallon per hour (gph) drip emitters were installed at each newly installed plant using ¼-inch tubing that stemmed from the ½-inch lateral lines. The ¼-inch micro-tubing was threaded through the existing protective wire plant cages to secure the line and keep the emitters out of the dirt. Five NCD personnel, two NPS personnel, and 43 volunteers worked to install these lines. The volunteers were from Friends of the Well, and teachers and students from Camp Verde and Mingus Union high schools. The following list summarizes the materials used in completing the drip irrigation system installation:

• Overland 1-inch PE secondary delivery line	600 linear feet
• ½-inch lateral PE lines	3500 linear feet
• ¼-inch micro-tubing	6000 linear feet
• 1-inch x ½-inch x 1-inch Spinloc Tees	12 each
• 1 gph drip emitters	1800 each
• ¼-inch barbed tees	900 each
• ¼-inch barbed connectors	900 each

In addition to the new installation, a complete testing and repair of the existing drip irrigation system occurred. Many rigid plastic fittings had broken, come apart, and/or were clogged while the system was not in use over the winter months. These needed to be replaced, reconnected, and/or cleaned while testing the system under pressure. Several fittings have seen considerable corrosion and scaling that required repair in order for the system to be operable. The 2-inch disc filters attached at the pumping stations also required a thorough cleaning to get the system up to working pressures. This maintenance took several days to complete.

Sprinkler System Overhaul

During the operation of the sprinkler system the previous season, it was noted that the application rate and distribution uniformity of the micro-sprinklers were not adequate to meet the plant water needs. These deficiencies arose from the hardness and suspended solids in the water clogging the sprinkler heads and the height of grasses blocking or otherwise impeding proper dispersion of water from the sprinkler. The previous micro-sprinklers used a ¼-inch micro tube that stemmed from the ½-inch lateral lines to the sprinkler head. The contraction from the ½-inch line to the ¼-inch lines resulted in significant friction losses that reduced the efficacy of each sprinkler. Additionally, these smaller lines were subject to scaling and clogging quicker than the larger diameter pipes. These micro-sprinklers were mounted on a plastic spike and extended only about 1 foot above the surface. The sprinkler head sprays a small jet of water at a low angle that does not spray over the top of the grass that had established.

The old sprinklers were replaced with a different type of sprinklers that had larger openings and were elevated above the top of the tall grasses. The new sprinklers tap directly into the ½-inch lines, eliminating compressive losses and allowing suspended sediment to pass. These water-lubricated gear-drive pop-up sprinklers (Figure 26) are attached to a riser system to spray over the top of the grasses.

Figure 26. New sprinklers installed

The photo shows one of the new sprinklers used for irrigation of the grassland meadow. The base is attached to a riser system at a height appropriate to spray over the tallest grasses. These can achieve a 40-foot diameter wetted area. The installed sprinklers use nozzles that deliver 2 gpm. In the photo to the left, a new sprinkler is seen installed next to the older type.

The new sprinklers have a greater flow rate than the previous type that allow for greater coverage of the grassland meadow; however, the greater flow rate reduces system pressures such that only a few sprinklers can be run at any one time. To alleviate this drop in pressure, ½-inch ball valves were installed on lateral lines to further partition the grassland and allow greater pressure within each section.
The following list summarizes the materials used to complete the installation of the new sprinklers:

½-inch barbed ball valves	33 each
360º gear-driven pop-up sprinklers	166 each
Sprinkler riser system	
½-inch barbed tees	166 each
½-inch to ¾-inch MPT Adapters	166 each
5-foot lengths of ½-inch rebar	166 each
3-foot lengths of ½-inch PE tubing	166 each
11-inch cable ties	332 each

With the new sprinkler installation, complete operation of the irrigation system now takes two days to complete.

2011 – Irrigation Maintenance

In 2011, work on the irrigation system included several days of maintenance of the existing drip lines and the modification of the supply lines running the sprinkler system. Due to inadequate water pressure, a second 1-inch supply line was installed alongside the original line to improve water pressure and flow rates. In addition, the end caps on the 1-inch supply lines were fitted with flush valves that could be opened to flush out sediment and air.

The irrigation ditches were also in need of maintenance this year. The main ditch from Montezuma's Well down through the western portion of the park sprung a leak to the point where the majority of the water was leaking into Beaver Creek. These leaks were formed about 200 feet downstream of the outlet of the Well and nearly all the water was gone before it left the west end of the Park. This repair resulted in the loss of one of the eight day watering cycles at the end of August. The repairs allowed the Park to irrigate once again by the beginning of September.

The west ditch was also seeing some erosion during 2011. Several grade-control structures were installed by one NCD and two NPS personnel with the help of the Coconino Rural Environment Corps (CREC). Grade-control weirs consisted of 8-16 inches in diameter rock. The weir spans the ditch channel but dips to only a few inches above the bed of the channel in the middle and rises up as the arms tie into the downstream portion of the ditch sidewalls (Figure 27).

Figure 27. Grade-Control Weir Installed in the West Ditch

Three of these loose rock weirs were installed in the west border ditch to provide grade-control.

Also of concern was where the west ditch tailwater spilled out. This tailwater ditch would spread out over an area that impacted the adjacent service road. To remedy this, an 8-inch dual-wall High Density PolyEthylene (HDPE) culvert pipe was installed to allow the water to flow under the service road before spreading out into the lower part of the field (Figure 28). Half-inch rebar was bent in a loop and installed at each end and in the middle of the pipe to anchor the pipe down. This pipe and the aforementioned loose rock weirs that comprise the west ditch improvements were not part of the original irrigation design. The installation is part of ongoing maintenance of the irrigation infrastructure and costs were not billed to Arizona Water Protection Fund.

Figure 28. Installation of the West Ditch Culvert

This dual-wall High Density Polyethylene (HDPE) pipe require anchors and good compaction along the bottom and sides to maintain its integrity as a culvert. The pipe was anchored at the ends and covered with a minimum of twelve inches of compacted backfill.

The following list summarizes the materials used to complete the sprinkler system upgrade, main ditch repair, and west ditch improvements (no time or materials were billed to the AWPF grant):

Total installation time	80 hours
1-inch tees	66 each
1-inch polyethylene supply line	750 linear feet
1-inch end caps with flush valve	14 each
Replacement Sprinkler Nozzles	160 each
Bentonite	one 50 lb bag
8-inch dual wall HDPE pipe	25 linear feet
½-inch rebar	10 linear feet

2012 – Irrigation Maintenance

In 2012, work on the irrigation system involved testing and repair of existing drip and sprinkler systems, replacing emitters, writing an Irrigation Operations Manual, training NPS personnel on system operation, securing pumps in place, and cleaning ditches. NPS with the assistance of CREC-YCC and volunteers created distribution channels at the terminus of both the west field ditch and the pollinator garden ditch which increased the watered area and enhanced native plant growth. Work on the irrigation system was performed by NCD, NPS personnel, and CREC and YCC volunteers during the weeks of March 14thand 26th, April 16th, April 30th, June 18th, and July 2nd. There were no other additions made to the irrigation system in 2012.

Operation of the irrigation system was turned over to NPS personnel in 2012. NCD staff provided an Irrigation Operation Manual and provided training on systems operation.

Operation of the irrigation system is an ongoing challenge. Rodents, mowing, and weed whacking often tear holes in the plastic irrigation lines which then need repair. Plugging of the drip emitters is still problematic, but replacement is fairly straightforward. There were mechanical problems with pump 2 during the summer which lead to poor irrigation performance for the central field set as well as the eastern sets in the grassland unit. Late in the season the pump was finally removed and was serviced. It worked fine after it was reinstalled for the final watering of the growing season. The time required to properly irrigate the grasslands is much more than initially anticipated. The grasslands need to be divided into seven different sections, each running for a minimum of 4 hours to achieve the flow and distribution required to function as designed. Better coverage and flow have been achieved at the price of increased manpower.

2013 Irrigation System Operation

Operation of the irrigation system was turned over to NPS personnel in 2012. Operation of the irrigation system continues to be a challenge. Leaks in the PVC and HDPE tubing and plugs continue to plague the system. The tubing and fittings are now beginning to photo-degrade, becoming brittle and breaking. Travertine buildup inside the lines results in the clogging of the micro-tubing and emitters. Rodents, mowing, and weed whacking have resulted in continual maintenance problems by causing rips and tears in the irrigation lines which then need repair. The Park Service has not decided yet whether they will continue to use the pumps and drip irrigation system for another year. Three years after the latest revegetation efforts, plantings should be established. Continued irrigation would be expected to increase growth, but have minimal impact on mortality rates.

In 2013, maintenance and operation on the active irrigation system involved the testing and repair of the existing drip and sprinkler systems along with maintenance of the pumps. NPS and ACE crews worked at the beginning of the spring to repair and replace emitters along the irrigation lines. The drip lines and sprinklers were then run two to three times a month through July. Monsoon rains eliminated the need for much of the irrigation in August, during which the system was only operated once

TASK 6 – REVEGETATION AND WILDLIFE IMPROVEMENT

Wildlife Improvement

2009 saw the construction of the wildlife improvements outlined in the design report. Efforts began with the construction of two brush piles along the riparian buffer area. These piles were created out of excess brush cleared out of the riparian buffer zone and placed into large piles to provide hiding cover for a variety of small native animal species (Figure 29).

Figure 29. Brush pile in the central field.

Two bat houses were constructed and installed in 2009 as well. The bat houses were placed on the southeast side of larger diameter ash and cottonwood trees approximately twelve feet up the trunk (Figure 30). The locations are shown in Figure 17.

Figure 30. Installed bat houses

Two raptor perch poles were manufactured for installation in the Central and West fields. The design deviated from the original plans. The new design incorporated 21ft. 4'X4' "Wolmanized" wood upright poles (of which 3ft. were buried), and twin redwood cross pieces, per a design for raptor perches in the Barn Owl Headquarters internet site by Bio-Diversity Products (Figure 31). The twin cross piece design was selected to address raptor preference toward perches that provide protection from attack from above and behind. In addition, discussion with NPS personnel regarding materials for the perches showed a preference for a wooden upright, vs. galvanized pole. The two raptor perch structures were mounted into concrete in 3 ft. deep excavations on October 8, 2009. Park Service personnel assisted with both installations. The locations of the installations are shown in Figure 17. Coordinates of the locations are: a) Central Field: 34° 38' 47.6" N 111° 45' 47.76" W (near the weather station); b) West Field: 34° 38' 47.68" N, 111° 45' 59.77" W.

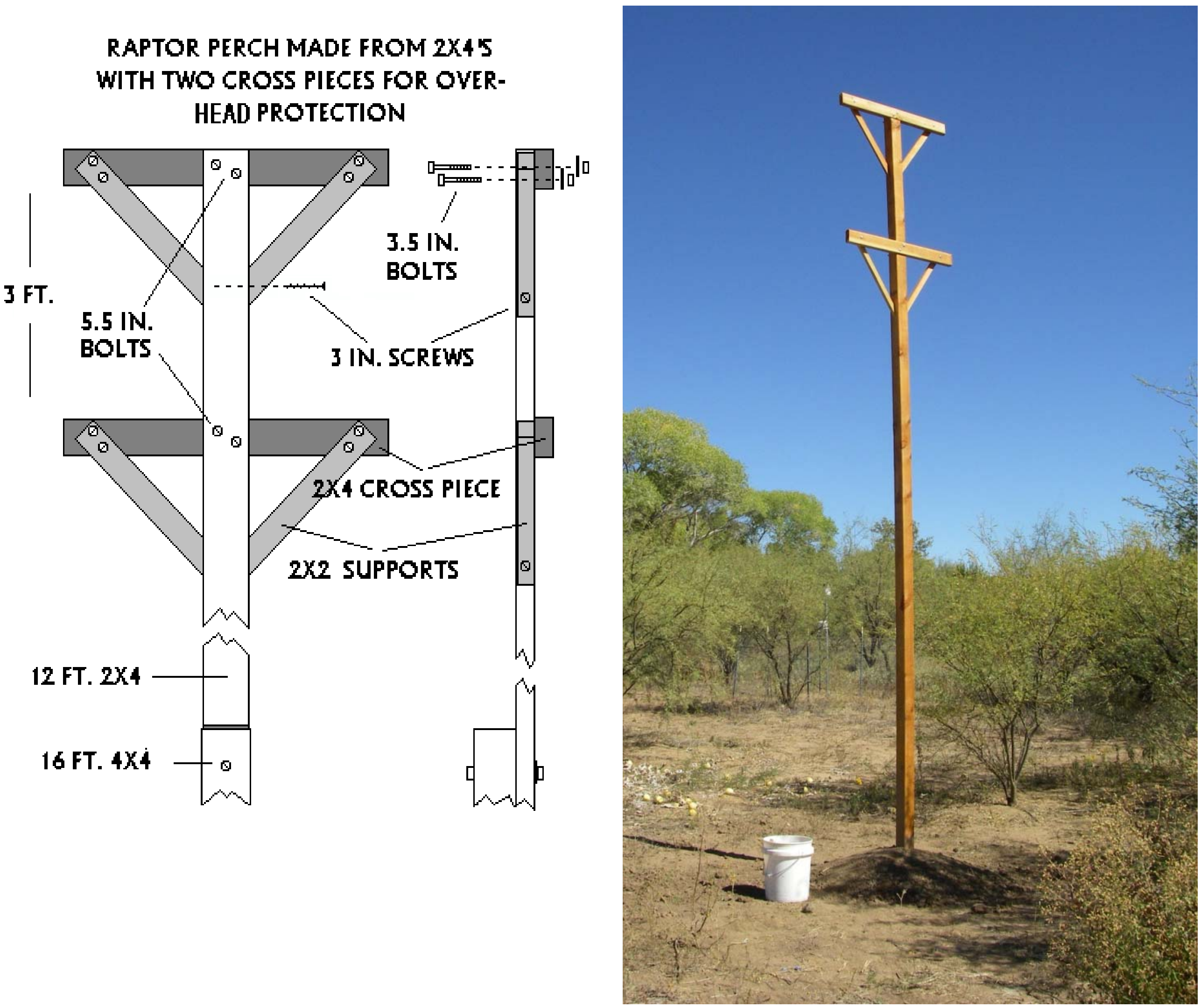

Figure 31. Raptor perch pole plans and installation in Central Field

2010 Revegetation Efforts

Revegetation efforts began the winter of 2010 and included seeding and containerized seedling plantings. Labor was provided by three NCD personnel, six NPS personnel and 63 volunteers who contributed 319 man-hours to the project. Volunteer organizations included: Friends of the Well, Camp Verde High School, Friends of Verde River Greenway, and Camp Verde Boy Scouts. Equipment included a mini-excavator with a 12-inch auger, backhoe, water tank on a trailer and miscellaneous vehicles. An aerial map with the locations of plantings is shown in Figure 32 .

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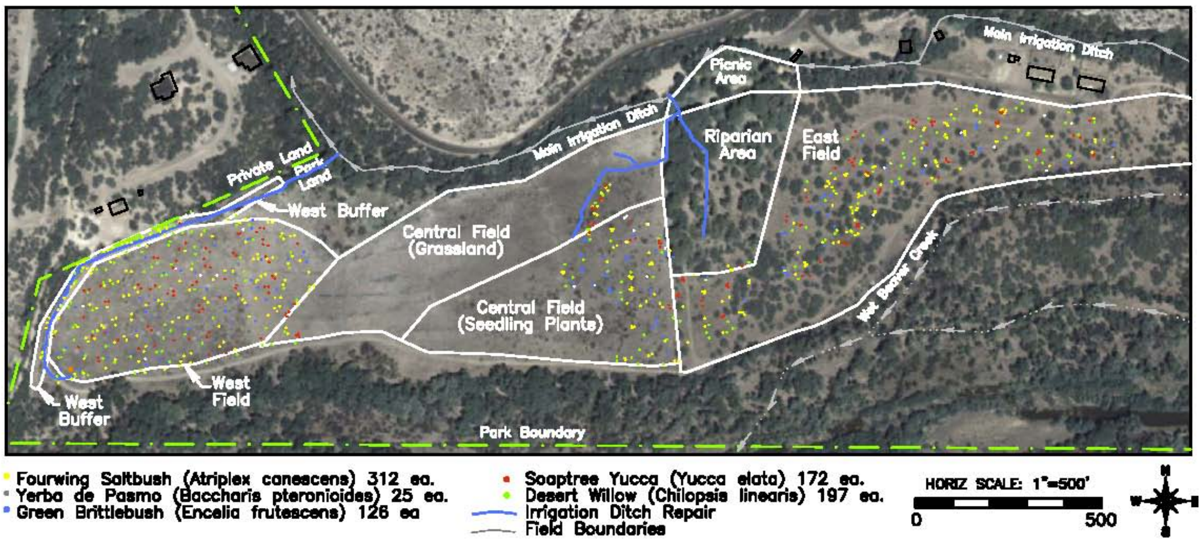

Figure 32. Field layout and containerized planting locations.

<u>Containerized Plantings</u>

A total of 832 containerized plants were grown by Tucson Plant Materials Center (USDA NRCS) and transported to the site (Figure 33). The plants consisted of four species of shrub and one species of tree (Table 15). Holes for the plantings were excavated using a 12-inch auger mounted on a mini-excavator. Water for the plantings was transported to the various planting areas using a 325-gallon tank on a flatbed trailer. It was transported from the tank to the plants in 5-gallon buckets. They were planted in the holes by hand and backfilled using a mix of the excavated native soil and water. Circular wire cages, two-feet high and approximately eighteen-inches in diameter were constructed to enclose the plants, protecting them from wildlife (Figure 34 and 35).

Individual planting locations were recorded using a mobile GPS unit and plotted over an aerial view photo for future monitoring efforts (Figure 32). Additional containerized plantings and grass/forbs seeding are planned for future planting sessions in summer 2010 and winter 2011.

Figure 33. Seedlings prior to planting

Table 15. Containerized plantings by area

Montezuma Well 2010 As-Built Plant List

Shrub Species	Common Name	West Field	Central Field	East Field	West Buffer	Ripar. Area	Total Shrubs
Atriplex canescens	Fourwing saltbush	132	37	97	26	20	312
Baccharis pteronioides	yerba de pasmo	6	9	8	2	0	25
Encelia frutescens	Green brittlebush	45	33	44	3	1	126
Yucca elata	Soaptree yucca	78	19	61	2	12	172
	Shrub Totals	261	98	210	33	33	635

Tree Species	Common Name	West Field	Central Field	East Field	West Buffer		Total Trees
Chilopsis linearis	Desert willow	77	27	64	15	14	197
				Total Plantings:			832

Figure 34. Augered holes, planting and final installation of plants

Figure 35. Installed plant along the west buffer and field

Seeding

A total of 157 pounds of native grass and forbs seed, consisting of a mix purchased from a commercial source and a variety of species collected locally by the NPS staff, were sown over disturbed areas throughout the project site. Seeding was conducted by NPS staff in December 2009 and January 2010. The soil in the areas to be planted was first loosened by pulling a chain-drag behind an ATV. Seed was then spread by hand-broadcasting at a rate of 6 pounds per acre and then raked into the soil (Figure 36). The seed mix is shown in Table 16.

Figure 36. Grass/forb seed planting

Photo shows chain-drag attachment for roughing soil prior to broadcasting seed, with Camp Verde High School volunteers hand-broadcasting seed from buckets. Photo: Sharon Kim, NPS.

Table 16. Grass/forb seed mix 2010

Common Name	Species		Amount
Purchased Seed			
sideoats grama	*Bouteloua curtipendula*		
Plains bristlegrass	*Setaria macrostachya*		
western weatgrass	*Elymus smithii*		
bottlebrush squirreltail	*Elymus elymoides*		
sand dropseed	*Sporobolus cryptandrus*		
		Total purchased seed:	**129 lbs**
Locally Collected Seed			
catclaw	*Acacia greggii*		
brownfoot	*Acourtia wrightii*		
purple three-awn	*Aristida purpurea*		
spidergrass	*Aristida ternipes*		
silver bluestem	*Bothriochloa saccharioides*		
black grama	*Bouteloua eriopoda*		
blue grama	*Bouteloua gracilis*		
winterfat	*Ceratoides lanata*		
yellow bee plant	*Cleome lutea*		
slender wheatgrass	*Elymus trachycaulus*		
New Mexico feathergrass	*Hesperostipa neomexicana*		
mucronate sprangletop	*Leptochloa panicea*		
hoary tansy aster	*Macheranthera tagetina*		
bush muhly	*Muhlenbergia porteri*		
Eaton's penstemon	*Penstemon eatonii*		
clammyweed	*Polanisia dodecandra*		
Griesbach bristlegrass	*Setaria griesbachii*		
spike dropseed	*Sporobolus contractus*		
sand dropseed	*Sporobolus cryptandrus*		
sacaton	*Sporobolus wrightii*		
slim tridens	*Tridens muticus*		
soaptree yucca	*Yucca elata*		
		Total locally collected seed:	**28 lbs**
		Total Seed:	**157 lbs**

Grassland Meadow Seeding

A second seeding was conducted during the week of July 26, 2010. This effort focused on seeding throughout the grassland meadow area by drill seeding or hand sown in areas with equipment limitations (Figure 37). The Tucson Plant Materials Center PMC), provided seeding equipment and labor to drill seed the grassland meadow area. The seed mix purchased from Granite Seed is shown in Table 17.

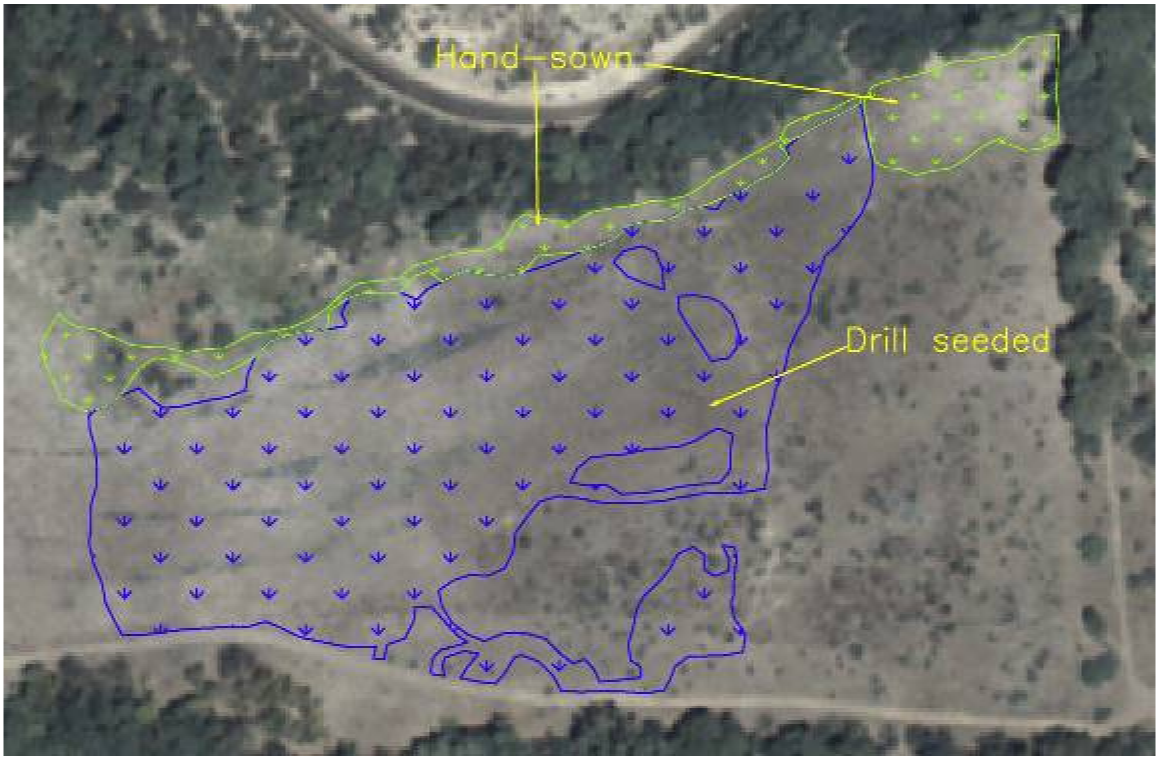

Figure 37. Grassland meadow seeding.

This seed mix was drill seeded on 4.6 acres and hand-sown on 0.9 acres for a total seeded area of 5.5 acres. Soon after the grass seeding took place, an inch of rain fell on the fields resulting in abundant germination (Figure 38).

Table 17. Grassland meadow seed mix

Season	Species	Scientific Name	% of Mix	lb PLS/ac for Pure Stand	lb PLS/ac for Pure Stand*	**lb PLS for 6 acres**
cool season	'Arriba' Western Wheatgrass	*(Pascopyrum smithii)*	15%	9	27	**24.3**
warm season	Sideoats Grama	*(Bouteloua curtipendula)*	25%	8	24	**36.0**
warm season	Green Sprangletop	*(Leptochloa dubia)*	25%	2	6	**9.0**
warm season	'Salado' Alkali sacaton	*(Sporobolus airoides)*	10%	1	3	**1.8**
cool/warm season	Sand Dropseed	*(Sporobolus cryptandrus)*	20%	0.5	1.5	**1.8**
warm season	'Grant' Cane Beardgrass	*(Bothriochloa barbinodis)*	5%	1.5	4.5	**1.4**
	TOTAL		**100%**			**74.3**
* Planting to be done by drill seeding, values have been increased by a factor of 3						12.38 lbs/acres

Figure 38. Grassland meadow later in the summer.

2011 Revegetation Efforts

The second phase of revegetation took place during the spring of 2011. This planting effort completed the major plantings planned for the project site and included plantings to replace individuals that did not survive the first year. Over 40 students and other volunteers assisted NCD and NPS staff with the revegetation efforts.

A rubber-tracked Bobcat excavator with hydraulic auger attachment was used to drill holes where plants were to be installed (Figure 39). This creates a large hole that, when backfilled, loosens the soil and could help root growth. The augered holes were nearly twice as deep as the pots that the plants were delivered in, which allows a greater zone of loosened soil around the roots, but care was maintained to ensure that the plants were installed such that the top of the containerized soil was at ground-level. This maintains the roots of the plants at proper depth to uptake soil moisture properly. Water was poured into the hole before and during plant installation to thoroughly moisten the surrounding soil and eliminate air pockets that may develop during backfilling.

Figure 39. Hydraulic auger for plant installation

A total of 871 trees, shrubs and other plants were installed during this spring effort (Table 18 & Figure 40).

Table 18. List of species planted

Shrub Species	Common Name		Number Planted
Atriplex canescens	Fourwing saltbush		42
Mahonia haematocarpa	Red barberry		5
Encelia frutescens	Green brittlebush		17
Ephedra viridis	Mormon tea		32
Lycium pallidum	Pallid wolfberry		204
Ribes aureum	Golden current		150
Yucca baccata	banana yucca		80
Yucca elata	Soaptree yucca		65
Ziziphus obtusifolia	Graythorn		102
		Totals	**697**
Tree Species			
Celtis reticulata	Netleaf hackberry		71
Chilopsis linearis	Desert willow		52
Sapindus saponaria	Soapberry Tree		3
Fraxinus veluntina	Arizona ash		36
Platanus wrightii	Arizona sycamore		7
Juglans major	Arizona walnut		5
		Totals	**174**
		Totals	**871**

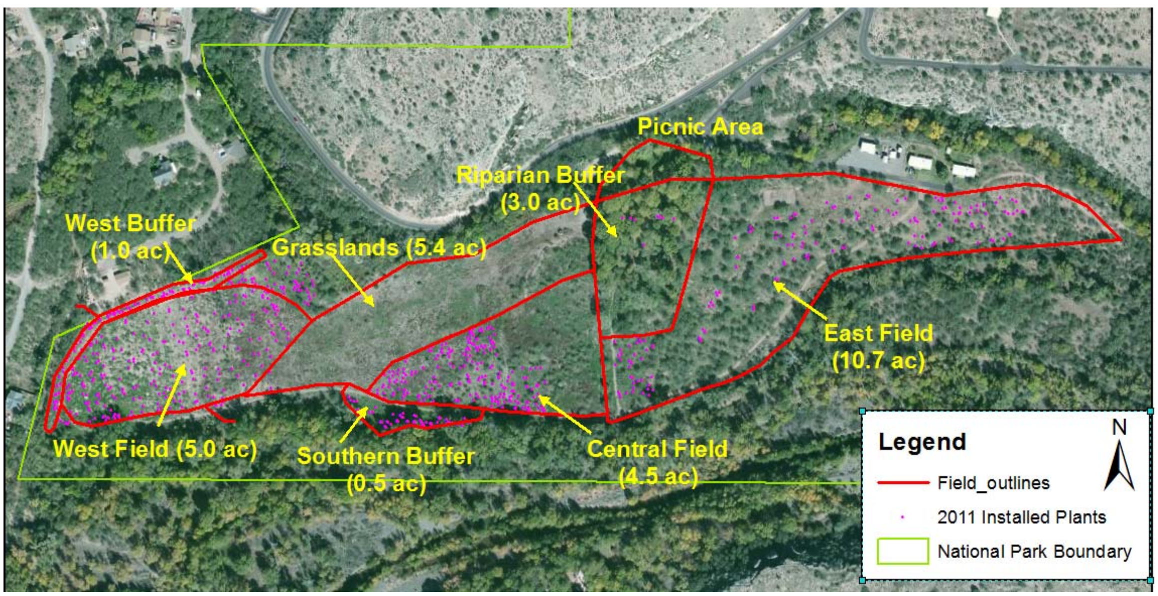

Figure 40. Location of installed plants spring 2011.

Later in the summer, additional plantings were added to the fields. Flagstaff Native Plant and Seed donated over 250 Sacaton grass seedlings to Natural Channel Design for installation at Montezuma Well. These seedlings were planted throughout the grasslands to augment previous plantings. Other additional plantings include 66 plants that replaced dead caged plants. These 66 plants included *Atriplex canescens (*Fourwing saltbush*), Baccharis pteronioides (*yerba de pasmo*), Dalea Formosa (*featherplume*), Ephedra viridis (*Mormon tea*), Rhus trilobata (*golden current*)* and *Yucca elata (*soaptree yucca). These plants were propagated with materials collected in the park and grown out by Verde River Growers.
Also planted were 19 hackberry (*Celtis reticulata)* containerized plantings that were installed along the trail leading from the riparian area down to the service road (Figure 41). These plants were installed with the help of volunteer labor including The Nature Conservancy LEAF program and Bev Sass, a VIP volunteer. The hackberries were installed with help of the Youth Conservation Corps (YCC). All of

these plants were installed as part of the planned attempt to extend some riparian vegetation along this section to connect the two riparian areas.

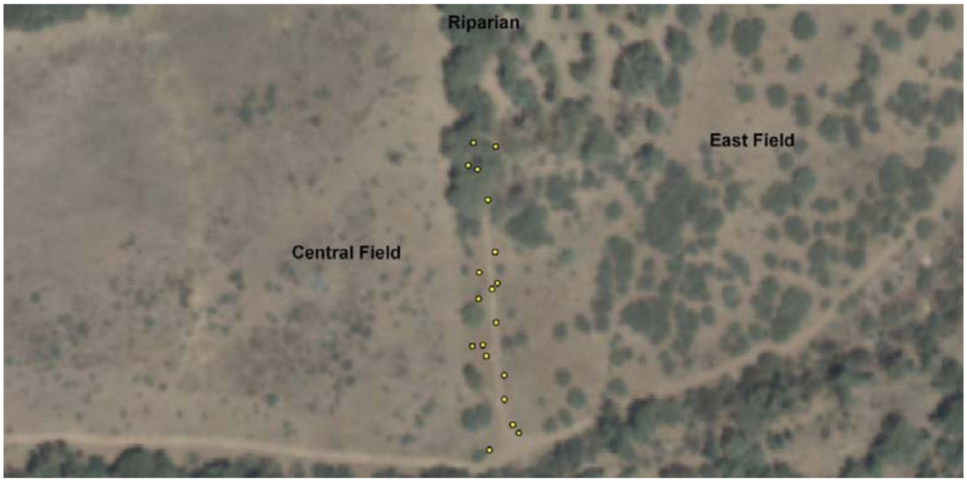

Figure 41. Additional hackberry plantings

2012 Revegetation Efforts

The week of December 6th, 2011, seed collected by the Park was sown throughout the project site. During the week of February 15th, additional seed was sown in the West field. Twenty resource islands areas were sown throughout the project on July 18 with help from CREC-YCC and TNC-LEAF. Resource islands (RIs) are small areas (314 sq. ft –circles with R=10 feet) that are sown at a high rate (10 lbs/ac.). The RIs were placed in locations that were lagging behind in native plant growth or that had dependable flood irrigation in case monsoon rains failed. Sacaton plugs were started on July 26th with the assistance of CREC-YCC. These plugs were grown out by local high schools and planted throughout the project in October.

2013 Revegetation Efforts

There were no additional revegetation plantings in 2013. In support of the revegetation efforts, additional, passive flood irrigation was installed along with the annual cleaning of the ditches. This effort was conducted by NPS, ACE crews, and volunteers (primarily CREC-YCC) with guidance from Natural Channel Design. During the summer of 2013, a feeder ditch called the west riparian ditch, was added along the Riparian main/pollinator ditch line. This ditch increased the watered area and will enhance native plant and grass growth. Over the next year or two, NPS plans on adding 2 or 3 small field ditches off the West field ditch to deliver more water to the middle of the West unit as the active irrigation drip lines are removed.

TASK 7 – ANNUAL MONITORING

Monitoring Protocols

The Monitoring Plan (developed as part of Task #2) describes the following monitoring protocols to measure success in reaching stated project goals and objectives. For more detailed descriptions including monitoring objectives and expectations, attributes to be measured, and monitoring methods and parameters, see project Monitoring Plan.

Invasive weed management - The goal of this protocol is to evaluate the effectiveness of applied treatments used to manage invasive species and to detect changes in invasive species density, abundance, and distribution over time. It is expected that invasive and non-native species density and distribution will decrease up to 80% during the life of the grant. Invasive weed management is monitored through annual measurement of vegetation plots in the project area

Revegetation Success - The goals are to evaluate the survival of plantings and vegetative communities created during restoration efforts. Revegetation monitoring determined if natural recruitment of native species improves in the project area. It is expected that 80% of all vegetation planted will survive and colonize the flood terrace. Percent cover is expected to increase annually as plants mature and natural recruitment begins. Revegetation success is measured through measurement of planted material survivorship and vegetation plot measurement.

Irrigation Conveyance and Distribution - The goal is to evaluate whether the turnouts and other irrigation repairs are conveying and distributing water efficiently and effectively and to detect any failures or additional work needed to the irrigation system. The irrigation system is monitored by visual assessment of line condition and output.

Wildlife Habitat Improvements – The goal of this protocol is to qualitatively measure the use of any habitat structures and to determine if increased cover attracts additional wildlife species. It is expected that the increase in vegetative cover and diversity will attract several species of birds, insects, and small mammals. Wildlife habitat improvements are monitored by visual observation of presence and use of structures as well through direct observation and game camara monitoring.

Photo Point Monitoring - The goal of photo point monitoring is to create a qualitative photo record of changes to the pasture and vegetation within the project area; and to document repairs and failures to the irrigation ditch. There is an expectation of increased native high terrace riparian vegetation and a decrease in non-native and invasive vegetation.
Photographs were taken annually to show vigor of revegetation efforts, changes to irrigation conveyance, and general site characteristics.

Wildlife Monitoring

The objectives for wildlife habitat monitoring are to evaluate the use of habitat structures and to determine if increased cover attracts additional wildlife species. Habitat structures include brush piles, raptor poles, and bat houses. It is expected that the increase in vegetative cover and diversity of native plant species will attract and provide habitat for several species of birds, insects, and small mammals. An increase in use of the project area is expected as revegetated areas link the riparian corridor to the upper floodplains.

Park staff has been involved in providing information on wildlife sightings and observations. Motion detection cameras were installed at two locations (Figure 46). In 2009, wildlife cameras captured images of mule deer, coyote, cottontail rabbit, and domestic housecats. During 2010, the cameras operated inconsistently with technical difficulties, including battery failure, and so do not provide a consistent record of wildlife use in the project area. However, cameras did capture more than 200 images of several animal species between September 1 and October 4, 2010, including white-tailed deer and several spotted fawns, striped and hog-nosed skunks, and javelina in addition to the species photographed in 2009.

Figure 42. Wildlife camera locations

In 2012 the camera captured over 1300 wildlife photos. The photos were primarily of deer and coyote, but also included rabbits, javelina, skunks, birds, and a fox plus a few cats and dogs in addition to a mountain lion (Figure 43).

Figure 43. Animal Species Photographed by Motion Detection Cameras During 2012

Figure 44. Butterflies Congregate on Milkweed Plants

Observers noted use of brush piles by songbirds and presence of raptors in the taller trees adjacent to the project area. Numerous species of butterflies and other pollinators were observed on the native milkweed and sunflower plants that are becoming established (Figure 44).

Monitoring Transects

Long-term monitoring transects were established to determine the composition of vegetation growing in the project area and to monitor the changes over time due to treatments and restoration. Three 900-foot long transects were located through the western, central and eastern pastures including the mesquite bosque and the grassland (Figure 46). Along each transect, thirty random sample plots were surveyed. Each plot was delineated by a 1-meter square frame as shown in Figure 45. Within the frame the number and species of rooted individuals was counted.

The naming convention indicates the transect number as T1 and STA 0 indicates the western most end of the transect, STA 900 indicates the eastern most end of the 900 foot long transect. To aid in identification in the field, each transect is marked by white PVC posts located at both ends as well as intermediate points (Figure 47).

These transects were used both to monitor the progress of the revegetation and invasive weed management. By quantifying and understanding the composition and density of the vegetation community at the beginning of the project we can track reduction of invasive weed species and increase in the native species that are expected to thrive once their non-native competition is eliminated.

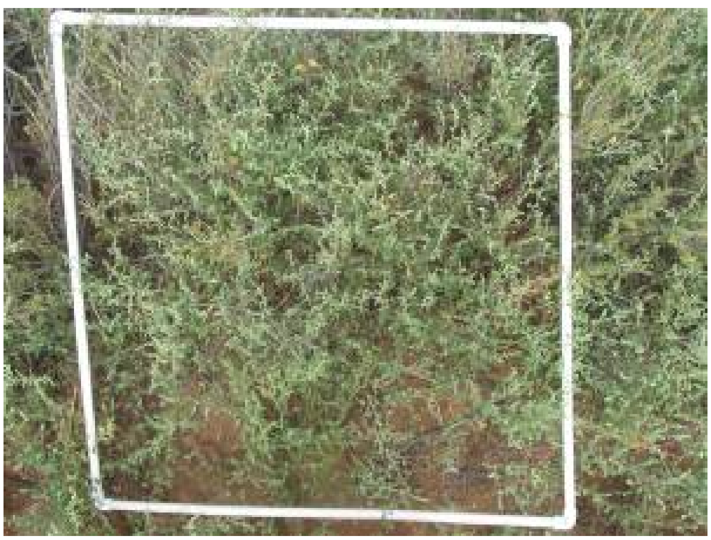

Figure 45. 1-meter sampling frame

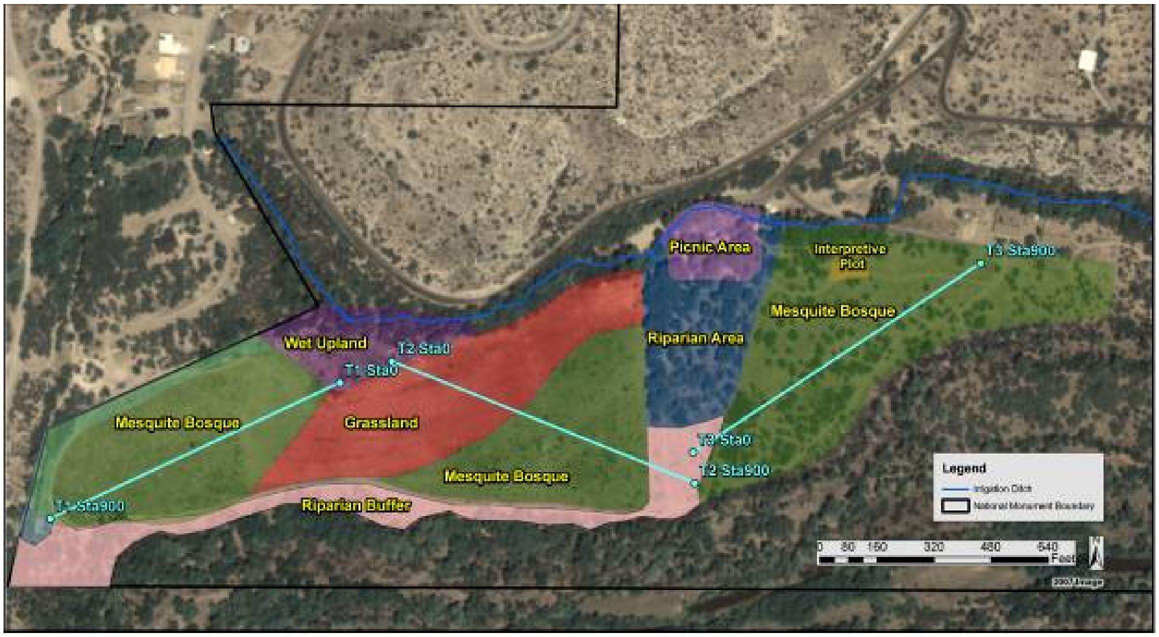

Figure 46. Project area with transect locations

Figure 47. Transect markers

Invasive Weed Management Monitoring

The goal of this protocol is to quantitatively measure changes in distribution and abundance of targeted invasive species within the project area. Thirty random one-meter square plots were sampled along each of the three transects. Random numbers were generated to select the stationing along the transect and lateral offset for each plot. Lateral offsets alternated left and right along the transect. Within each one-meter square plot the number and species of rooted stems was visually estimated and placed in a category. Each species is assigned a category based on the percentage of plots where the species is found: Scattered (S) 0-10%, Light (L) 11-20%, Moderate (M) 21-40%, or Heavy (H) >40%.

The assumptions at the beginning of the project were as follows. It is expected that all areas will experience a decline in the density and distribution of invasive weed species. It is also expected that the native plants in the project area will increase once they are no longer crowded by dense stands of invasive species such as Russian thistle (*Salsola iberica*) and there will be an increasing trend in the density and distribution in native vegetation.

Transect 1

Transect 1 bisects the western field. Silverleaf nightshade continues to dominate the field (Table 19). The extent of silverleaf nightshade has increased sharply from 2008 (37%) to 2012 (70%) while the degree of infestation has remained around 30%. The extent of infestation for Russian thistle was reduced to just 23% in 2011 and 2012, down from 73% in 2010. The degree of infestation for Russian thistle was reduced to 3%, a large decrease from 2008. Dallisgrass extent is up sharply in 2012 along Transect 1. Johnsongrass and field bindweed have increased slightly in 2012 while the rest of the target species remain at low levels.

Table 19. Transect 1, West Field Target Species for 2008 through 2012

Common Name (Scientific Name)	Baseline Monitoring 2008		Annual Monitoring 2009		Annual Monitoring 2010		Annual Monitoring 2011		Annual Monitoring 2012	
	Extent	Degree	Extent	Degree	Extent	Degree	Extent	Degree	Extent	Degree
Bull thistle (Cirsium vulgare)	0%	0%	7%	0%	0%	0%	3%	0%	0%	0%
Field bindweed (Convolvulus arvensis)	17%	17%	0%	0%	3%	0%	0%	0%	13%	7%
Flixweed (Descurainia sophia)	0%	0%	0%	0%	7%	0%	3%	0%	0%	0%
Common horehound (Marrubium vulgare)	3%	0%	0%	0%	3%	0%	0%	0%	0%	0%
Narrowleaf plantain (Plantago lanceolata)	0%	0%	0%	0%	0%	0%	3%	0%	0%	0%
Russian thistle (Salsola iberica)	77%	73%	37%	27%	73%	20%	23%	10%	23%	3%
Silverleaf nightshade (Solanum elaeagnifolium)	37%	30%	57%	30%	67%	27%	63%	33%	70%	33%
Goathead (Tribulus terrestris)							0%	0%	7%	0%
Ripgut brome (Bromus diandrus)	0%	0%	0%	0%	27%	10%	3%	3%	0%	0%
Smooth brome *(Bromus inermis)*	0%	0%	7%	7%	0%	0%	0%	0%	0%	0%
Red brome (Bromus rubens)	0%	0%	10%	7%	3%	0%	13%	3%	0%	0%
Bermudagrass (Cynodon dactylon)	10%	10%	10%	10%	7%	3%	0%	0%	0%	0%
Dallisgrass (Paspalum dilataum)	0%	0%	0%	0%	10%	3%	0%	0%	50%	17%
Johnsongrass (Sorghum halepense)	3%	0%	7%	3%	7%	3%	10%	7%	17%	10%

*****Puncturevine (Tribulus terrestris) was added to the list in 2011

Transect 2

Transect 2 bisects the central field. The extent of infestation for Russian thistle has decreased sharply since 2008, from 80% to 20%, and no heavy infestations were found in 2012 along Transect 2. However, both the extent and degree of silverleaf nightshade have increased since 2008. Field bindweed, red brome, Dallisgrass, and Johnsongrass have also increased in 2012. The other target species were at low levels.

Table 20. Transect 2, Central Field Target Species for 2008 through 2012

Common Name (*Scientific Name*)	Baseline Monitoring 2008		Annual Monitoring 2009		Annual Monitoring 2010		Annual Monitoring 2011		Annual Monitoring 2012	
	Extent	Degree	Extent	Degree	Extent	Degree	Extent	Degree	Extent	Degree
Bull thistle (Cirsium vulgare)	3%	0%	3%	0%	0%	0%	7%	0%	0%	0%
Field bindweed *(Convolvulus arvensis)*	17%	3%	20%	0%	20%	7%	20%	3%	23%	3%
Flixweed (Descurainia sophia)	0%	0%	0%	0%	10%	10%	3%	0%	0%	0%
Common horehound (Marrubium vulgare)	7%	3%	7%	0%	3%	0%	13%	3%	0%	0%
Narrowleaf plantain (Plantago lanceolata)	17%	13%	3%	0%	0%	0%	10%	0%	0%	0%
Russian thistle *(Salsola iberica)*	80%	60%	83%	40%	63%	30%	10%	3%	20%	0%
Silverleaf nightshade (Solanum elaeagnifolium)	27%	17%	37%	13%	23%	3%	30%	7%	43%	20%
Goathead (Tribulus terrestris)							3%	0%	0%	0%
Ripgut brome (Bromus diandrus)	0%	0%	0%	0%	30%	17%	47%	30%	0%	0%
Smooth brome (Bromus inermis)	0%	0%	7%	3%	0%	0%	0%	0%	0%	0%
Red brome *(Bromus rubens)*	0%	0%	20%	7%	0%	0%	0%	0%	10%	3%
Bermudagrass (Cynodon dactylon)	3%	3%	10%	7%	7%	3%	3%	0%	0%	0%
Dallisgrass (Paspalum dilataum)	7%	7%	7%	7%	0%	0%	0%	0%	17%	7%
Johnsongrass (Sorghum halepense)	0%	0%	0%	0%	10%	10%	13%	3%	23%	7%

Transect 3
Transect 3 bisects a well established young mesquite bosque. The vegetation in the understory is less dense and contains more grasses and composites than the other two transects. However, silver leaf nightshade remains at high levels for both extent and degree of infestation. Russian thistle was not found along this transect in the last two years. Red brome has decreased while the other target species remain at low levels of infestation.

Table 21. Transect 3, East Field Infestation of Target Species for 2008 through 2012

Common Name (*Scientific Name*)	Baseline Monitoring 2008		Annual Monitoring 2009		Annual Monitoring 2010		Annual Monitoring 2011		Annual Monitoring 2012	
	Extent	Degree	Extent	Degree	Extent	Degree	Extent	Degree	Extent	Degree
Bull thistle (Cirsium vulgare)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Field bindweed (Convolvulus arvensis)	3%	0%	0%	0%	3%	0%	3%	0%	3%	0%
Flixweed *(Descurainia sophia)*	0%	0%	3%	3%	13%	7%	3%	0%	0%	0%
Common horehound *(Marrubium vulgare)*	0%	0%	3%	0%	0%	0%	0%	0%	3%	0%
Narrowleaf plantain (Plantago lanceolata)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Russian thistle (Salsola iberica)	40%	17%	70%	37%	27%	0%	0%	0%	0%	0%
Silverleaf nightshade (Solanum elaeagnifolium)	97%	83%	83%	40%	93%	73%	91%	60%	93%	57%
Goathead (Tribulus terrestris)							13%	0%	3%	0%
Ripgut brome (Bromus diandrus)	0%	0%	0%	0%	83%	73%	46%	43%	0%	0%
Smooth brome (Bromus inermis)	0%	0%	7%	7%	7%	7%	0%	0%	0%	0%
Red brome *(Bromus rubens)*	27%	10%	73%	60%	20%	0%	49%	43%	13%	0%
Bermudagrass *(Cynodon dactylon)*	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Dallisgrass (Paspalum dilataum)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Johnsongrass (Sorghum halepense)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 48 is a graphical representation of the efficacy of the eradications efforts since 2008 on six of the most widely distributed weed species. Russian thistle has responded very well to treatment, showing a large decline in both extent and degree of infestation on all transects. Silverleaf nightshade has not responded to treatment and has increased in the west and central fields while remaining essentially unchanged in the east field. Johnsongrass and Dallisgrass are also increasing in the west and central fields. Red and ripgut brome appear to be on the decline but this is mainly due to timing of the surveys. There is still a fairly large population of these spring annual grasses, particularly in the east field. Weed management activities will be needed for the foreseeable future in order to ensure that declining populations continue to decline and to focus management efforts on the expanding silverleaf nightshade population.

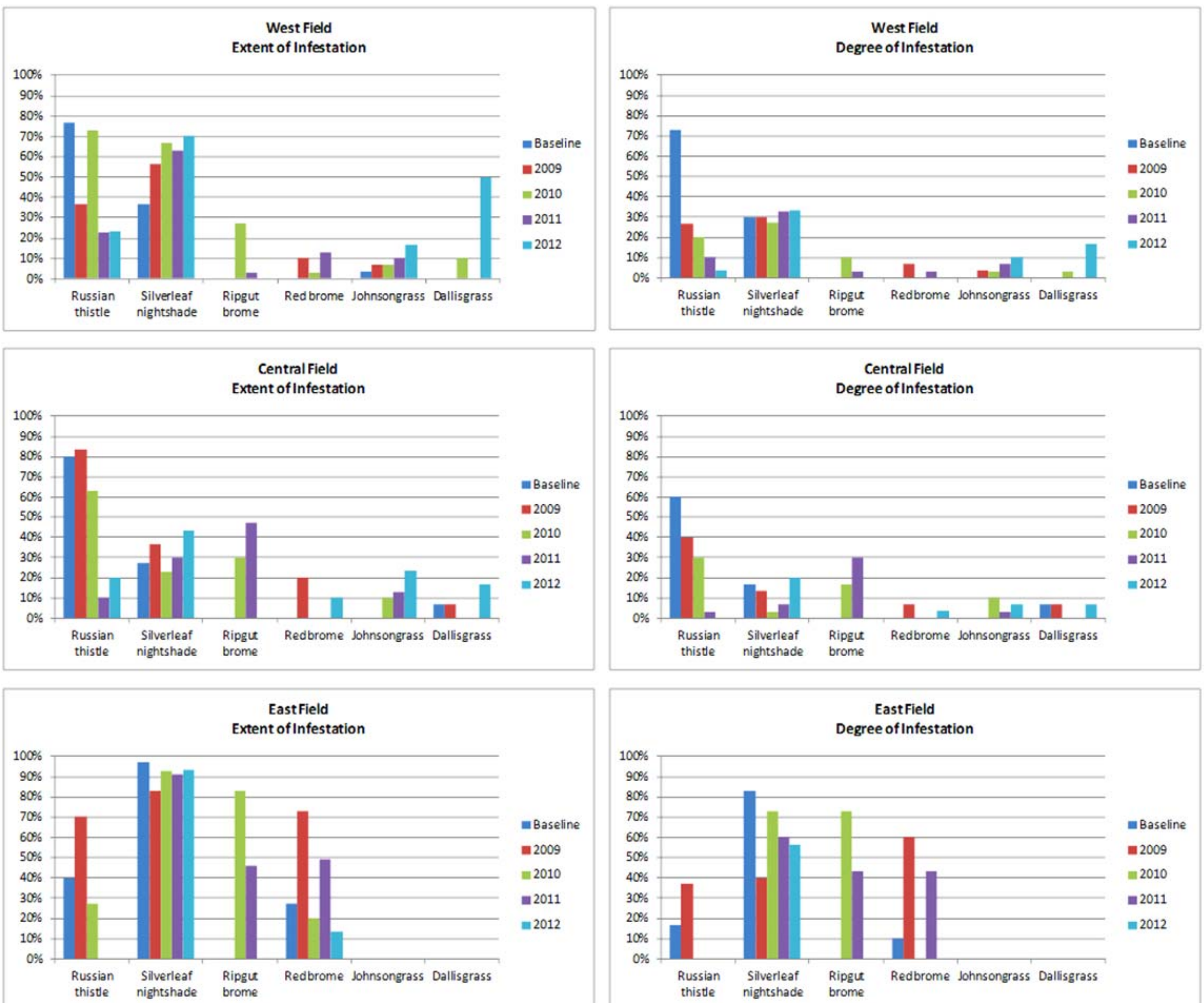

Figure 48. Efficacy of Weed Eradication for the Six Most Prevalent Species.

Vegetation Community Monitoring

Changes in vegetation community composition were also measured using data collected along the transects. Species were divided into invasive or native and perennial or annual classes and entered as one of eight classifications; 1) invasive/non-native annual grasses, 2) invasive/non-native annual forbs, 3) invasive/non-native perennial grasses, 4) invasive/non-native perennial forbs, 5) desired native annual grasses, 6) desired native annual forbs, 7) desired native perennial grasses, and 8) desired native perennial forbs. Number of stems per plot were recorded to estimate cover and the presence/absence of a species within a plot was utilized to occurrence rate.

There is upward trend in both the number of native species and their occurrences over the years. However, there has also been an increase in non-native perennial forb occurrences, mostly due to an increase in silverleaf nightshade. Figure 49 shows the number of occurrence in each of the eight classes for 2009 through 2012. Figure 50 shows the number of species found in each of the eight classes for all four years of monitoring.

Table 22 provides a list of all the species, native and non-native, that have been found during monitoring and the year they were found.

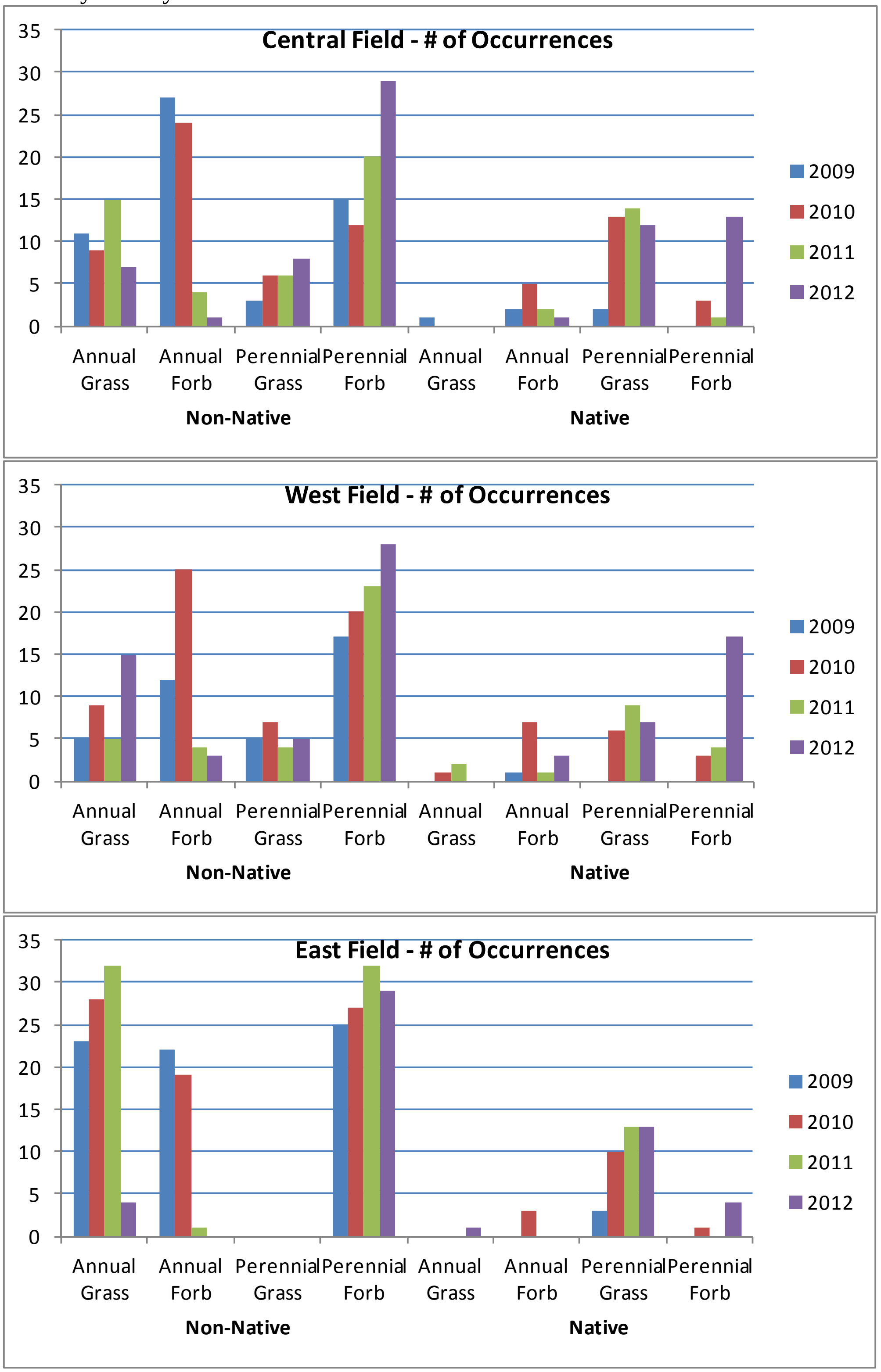

Figure 49. Summary of vegetation monitoring (number of occurrences), 2009-2012

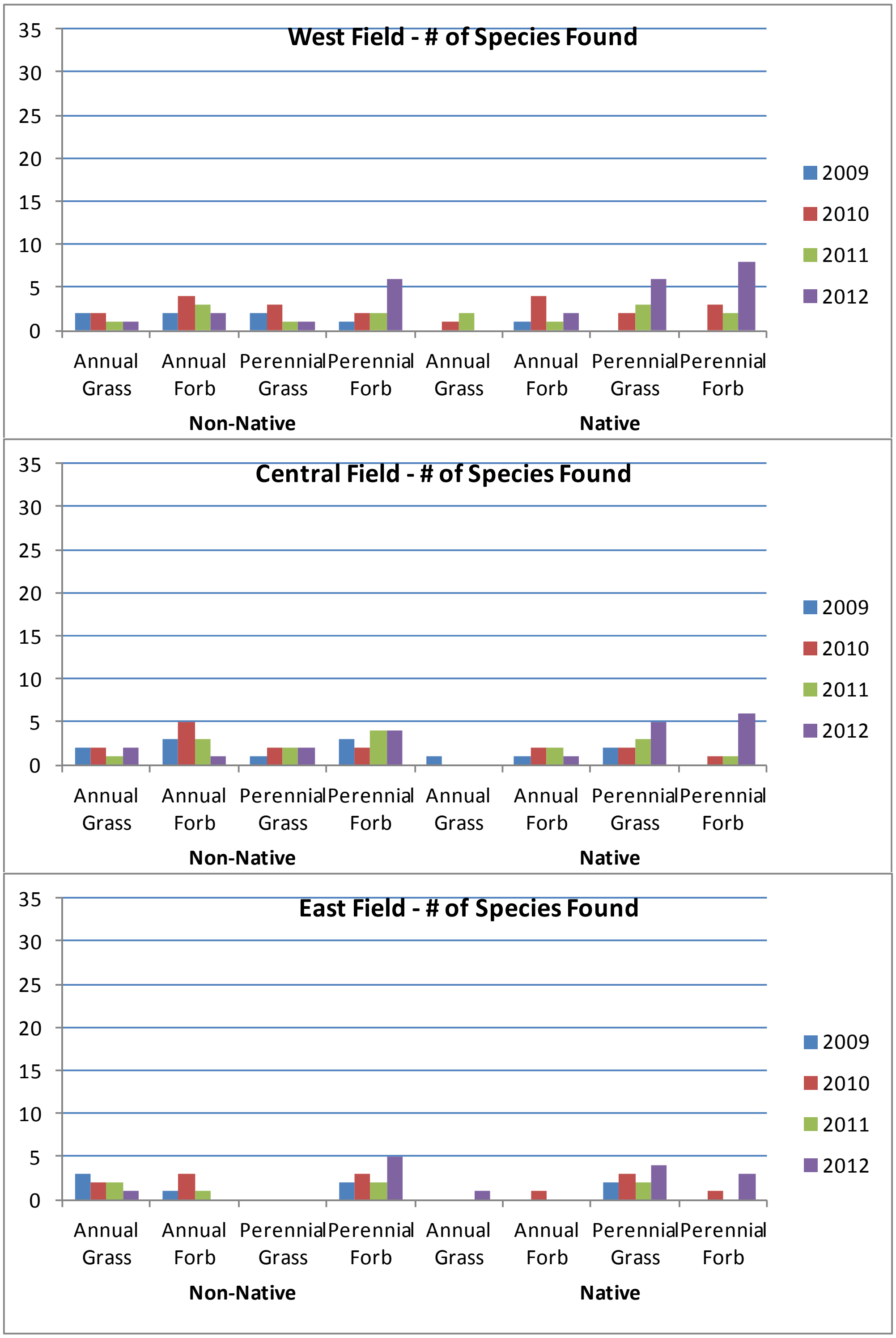

Figure 50. Summary of vegetation monitoring (number of species) 2009 – 2012.

Table 22. Plant species found during vegetation monitoring for each year of monitoring.

Symbol	Species Name	Common Name	2009		2010	2011	2012
AECY	*Aegilops cylindrica*	jointed goatgrass	X	**Non-Natives**			
AM sp.	*Ambrosia sp.*	ragweed			X		X
BRDI	*Bromus diandrus*	ripgut brome				X	X
BRIN	*Bromus inermis*	smoothe brome	X		X	X	
BRRU	*Bromus rubens*	red brome	X		X	X	X
CIVU	*Cirsium vulgare*	bull thistle	X		X	X	
CHAL	*Chamaesyce albomarginata*	whitemargin sandmat					X
COCA	*Conyza canadensis*	Canadian horseweed					X
COAR	*Convolvulus arvensis*	field bindweed	X		X	X	X
CYDA	*Cynodon dactylon*	Bermudagrass	X		X	X	
DESO	*Descurainia sophia*	flixweed			X	X	
LOPE	*Lolium perenne*	perennial ryegrass					X
MAVU	*Marrubium vulgare*	horehound	X		X	X	X
MEOF	*Melilotus officinalis*	sweetclover					X
PADI	*Paspalum dilatatum*	dallisgrass			X		X
PLLA	*Plantago lanceolata*	narrowleaf plantain	X			X	
SAIB	*Salsola tragus*	Russian thistle	X		X	X	X
SOEL	*Solanum elaeagnifolium*	silverleaf nightshade	X		X	X	X
SO sp.	*Sonchus sp.*	sowthistle			X		
SOHA	*Sorghum halepense*	Johnsongrass	X		X	X	X
TRTE	*Tribulus terrestris*	puncturevine					X
ALIN	*Allionia incarnata*	trailing windmills		**Natives**		X	X
AM sp.	*Amaranthus sp.*	pigweed			X		
AR sp.	*Aristida sp.*	three-awn			X	X	X
ASSU	*Asclepias subverticillata*	horsetail milkweed			X	X	X
BOBA	*Bothriochloa barbinodis*	cane bluestem				X	X
BOSA	*Bothriochloa sacchariodes*	silver bluestem	X		X	X	
BOBA2	*Bouteloua barbata*	sixweeks grama					X
BOCU	*Bouteloua curtipendula*	sideoats grama				X	X
CA sp.	*Calliandra sp.*	stickpea					X
CU sp.	*Cucurbita sp.*	gourd					X
ELEL	*Elymus elymoides*	squirreltail grass	X			X	X
EU sp.	*Euphorbia sp.*	spurge					X
FE sp.	*Festuca sp.*	fescue	X				
GUSA	*Gutierrezia sarothrae*	snakeweed			X		
HEAN	*Helianthus annuus*	common sunflower	X		X	X	
HOJU	*Hordeum jubatum*	foxtail barley					X
IPCO	*Ipomoea costellata*	morning-glory					X
LOWR	*Lotus wrightii*	Wright's deervetch					X

Revegetation Success
The goal for monitoring the success of revegetation efforts is to evaluate the survival and establishment of plantings and an increase in native vegetation during restoration efforts.

Native Grass Seeding
Grass seed was planted prior to the summer monsoon with a seed mix provided by Natural Resources Conservation Service (NRCS) Plant Materials in Tucson. Seeded areas were watered with sprinkler irrigation to supplement scattered rain patterns. By mid-September 2010, young seedlings could be seen filling in areas where weeds had been removed and in 2012 the grasses were thriving (**Error! Reference source not found.**). Open areas have been filled in with supplemental plantings and grass species are becoming more frequent in the transect monitoring as well.


September 2010


September 2011


August 2012 – Grasses have increased in density and height

Figure 51. Native grass establishment

Containerized Plantings
A total of 799 containerized trees and shrubs comprised of five species were planted in February 2010. In October 2010, plants were counted and an 84% overall survivorship was recorded. In spring of 2011, an additional 1304 shrubs and trees, representing the original five plus 15 additional species, were planted. Table 23 lists each species and its survival rate, along with the overall survival of all plantings. When measured in the fall 2011, the survival rate for all the plantings was 51% and in 2012 the survivorship was 42%.

There are likely several factors contributing to the high plant mortality. The most likely is inadequate soil moisture during the growing season (April 1 to October 1). Although the plants were watered according to the established schedule in 2010 and 2011 (every eight days during the growing season, except when there was adequate precipitation), we believe this was not frequent enough for proper establishment in such a hot, dry climate. The soil moisture probes (see following section for more detail) indicate that surface soil moisture levels were inadequate for much of the growing season for all three years (2010 through 2012). Rooting depth moisture levels were generally higher; however there may have been significant periods of time between monitoring periods when soil moisture levels were low enough to stress new plantings.

Other factors that contributed to the lower than expected success rate include:

- some of the 2011 plants arrived onsite in poor condition;
- breaks and plugs in the irrigation system prevented thorough watering;
- hot and dry conditions that persisted throughout the summer in 2011 and the first half of 2012, especially between watering cycles when irrigation could not be performed;
- attack by aphids, ants, and gophers; and
- foraging by wildlife when plant cages blew away, damage by people or vehicles during mowing activities

Plant mortality occurred in a random pattern and is not concentrated in any particular area or correlated with any one irrigation system. Of the small one-gallon plants that were planted in February 2010, many have experienced substantial rates of growth. The density and distribution of desirable native species is expected to increase as plants mature and natural recruitment begins to occur. Figure 52 illustrates the location of the surviving trees and shrubs.

Table 23. Survivorship of Native Plant Species

Common Name (Scientific Name)	Planted Spring 2010	Surviving Fall 2010	Percent Surviving 2010	Total Planted	Total Surviving Fall 2011	Percent Surviving 2011	Total Surviving Fall 2012	Percent Surviving 2012
Fourwing saltbush (Atriplex canescens)	299	285	95%	347	244	70%	233	67%
Yerba de pasmo (Baccharis pteronioides)	25	17	68%	28	8	29%	7	25%
Red barberry (Mahonia haematocarpa)				6	0	0%	0	0%
Green brittlebush (Encelia frutescens)	125	72	58%	141	9	6%	5	4%
Mormon tea (Ephedra viridis)				84	25	30%	16	19%
Pallid wolfberry (Lycium pallidum)				195	124	64%	90	46%

Mexican cliffrose (Purshia mexicana)				1	0	0%	0	0%
3-leaf sumac (Rhus trilobata)				2	2	100%	2	100%
Golden current (Ribes aureum)				227	144	63%	129	57%
Banana yucca (Yucca baccata)				84	75	89%	62	74%
Soaptree yucca (Yucca elata)	165	146	89%	197	138	70%	111	56%
Gray thorn (Ziziphus obtusifolia)				181	42	23%	28	15%
Tree Species								
Cottonwood (Populus sp.)				1	1	100%	0	0%
Netleaf hackberry (Celtis reticulata)				196	75	38%	54	28%
Desert willow (Chilopsis linearis)	185	148	80%	217	127	59%	109	50%
Table 23 continued:								
Common Name (Scientific Name)	Planted Spring 2010	Surviving Fall 2010	Percent Surviving 2010	Total Planted	Total Surviving Fall 2011	Percent Surviving 2011	Total Surviving Fall 2012	Percent Surviving 2012
California buckthorn [Coffeeberry] (Frangula californica)				1	1	100%	0	0%
Arizona ash (Fraxinus veluntina)				100	30	30%	25	25%
Sycamore (Platanus wrightii)				80	17	21%	12	15%
Soapberry tree (Sapindus saponaria)				10	4	40%	2	20%
Walnut (Juglans major)				5	3	60%	3	60%
Totals	799	668	84%	2103	1069	51%	888	42%

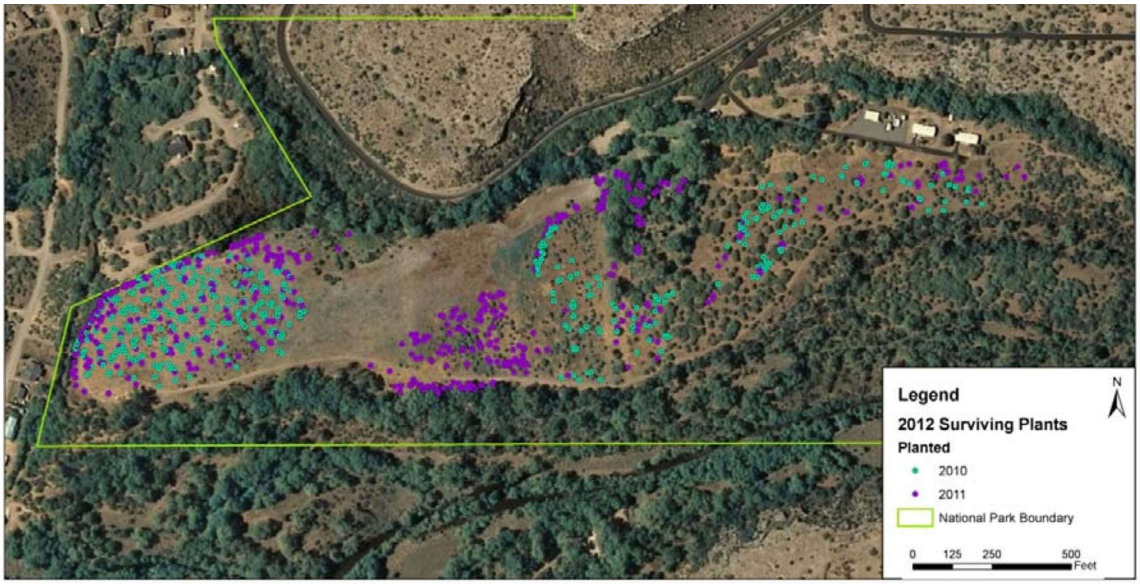

Figure 52. Location of Surviving Trees and Shrubs Planted in 2010 and 2011.

Photo Point Monitoring

Ten photo points were established around the project area Figure 53. These photo points were placed throughout the project area with the purpose of recording broad changes to vegetation over time. The following figures (Figure 54 through Figure 62) dispay the 2008 photos compared to the existing conditions photos.

Figure 53. Photo Point Locations

Figure 54. Photo Point 1 in Riparian Buffer, View to the East.

Native grasses are beginning to replace non-native Johnsongrass

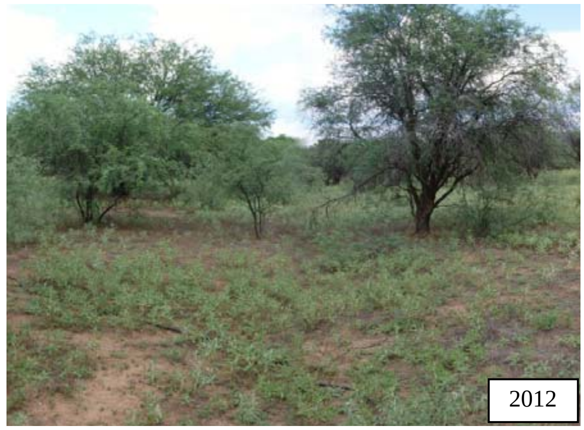

Figure 55. Photo Point 2 in East Field, View to the Northeast.

Silverleaf nightshade can be seen growing in the 2012 photo

Figure 56. Point 3 in NE Corner of Central Field, View to the Southwest.

Native grasses are growing in to replace non-native Johnsongrass and Russian thistle. The trail and demonstration garden are seen in the 2012 photo.

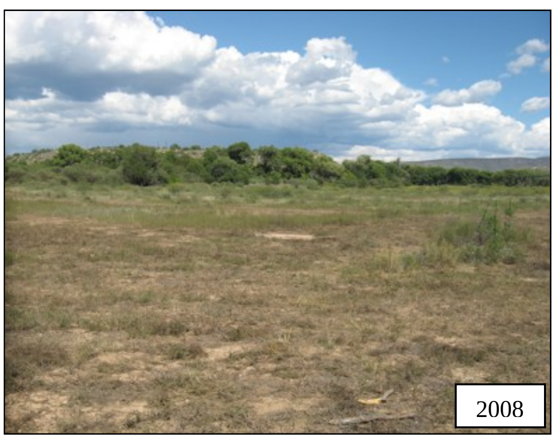

Figure 57. Photo Point 5 – View to the Northeast

This photo is taken from STA 0 on transect 1. This area receives irrigation from the west boundary ditch.

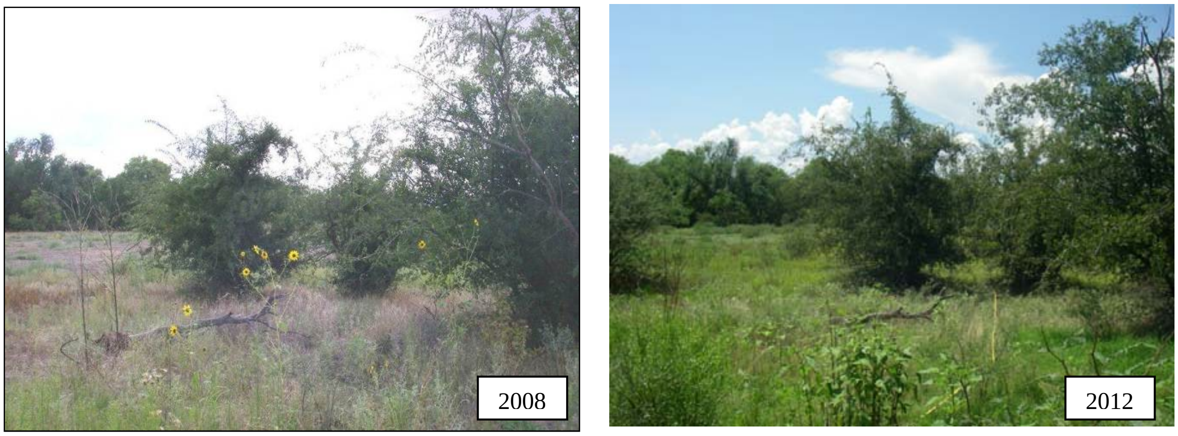

Figure 58. Photo Point 6, View to the southwest

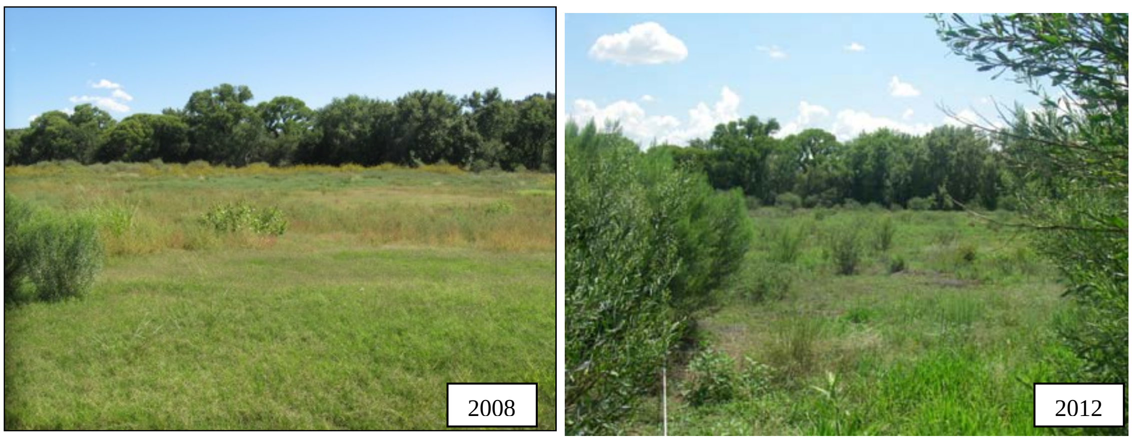

Figure 59. Photo Point 7. Looking South.

The Bermudagrass visible in the lower half of the 2008 photo has been replaced with natives in 2012.

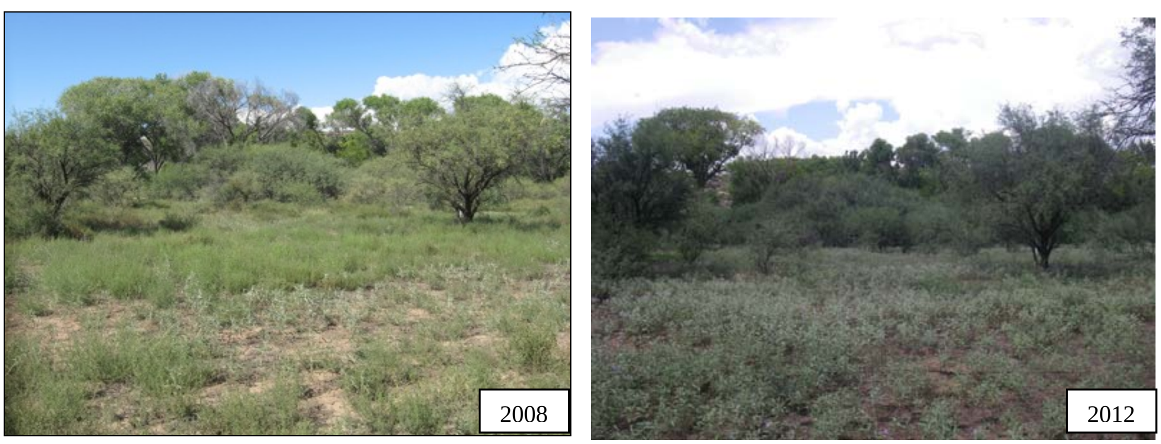

Figure 60. Photo Point 8 – View to the North

The main difference at this photo point has been the elimination of Russian thistle and the expansion of silverleaf nightshade. No grasses have been sown here.

Figure 61. Photo Point 9 - Looking north.

Again at this photo point, Russian thistle has been greatly reduced, but no additional seeding has been done here.

Figure 62. Photo Point 10 - looking southwest.

The Russian thistle that was the dominant vegetation in 2008 has been essentially eliminated in the 2012 photo and native forbs and grasses are filling in.

TASK 8 – PUBLIC OUTREACH IMPLEMENTATION

Public outreach activities during the project took on a variety of forms, from public presentations, volunteer work days, workshops and signage.

2009 Public Outreach

On April 16, 2009, Natural Channel Design personnel Allen Haden and Stephanie Yard, in conjunction with NPS personnel Dennis Casper, made a presentation at the Arizona Riparian Council Meeting in Camp Verde, AZ. The presentation was a PowerPoint slide show entitled, *Weed Management Strategy to Support Restoration Efforts along Wet Beaver Creek at the National Park Service Montezuma Well Unit*. Figure 63 shows the title slide from the presentation.

Figure 63. Title slide from 2009 ARC presentation

2010 Public Outreach

Planting of seedling plants during the first planting phase of the project in February 2010 utilized volunteers from three local volunteer organizations and a local high school. Prior to work, a background summary and purpose of the project was presented to the volunteers. Organizations contributing labor included; Friends of the Well, Camp Verde High School, Friends of Verde River Greenway, and Camp Verde Boy Scouts. There were a total of 63 volunteers that worked a total of 319 man-hours. The National Park Service published a news release on their web site regarding the volunteer efforts of the Camp Verde high school students (Figure 64).

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Volunteers Help Restore 30 Acres Of Parkland

By Sharon Kim, Acting Chief of Natural Resources Management
February 26, 2010

Students from Camp Verde High School planting native plants as part of the restoration project. NPS photo.

Nearly 40 volunteers worked with park staff to sow seed and plant 817 plants over 30 acres at the Montezuma Well riparian restoration project last week.

As part of this effort, twenty-one students from Camp Verde High School planted 385 plants in the five-acre west field unit. The native plants that were planted include desert willow, four-winged saltbush, green brittlebush, soaptree yucca, and yerba de pasmo. The native seed sown included 35 different species of native plants collected in the park by volunteers and park staff over the past two years. Last week's volunteers also built and installed cages for the plants to protect them from wildlife. As the year progresses, the students and other volunteers will continue to help the park control invasive plants around the young plants.

This large planting project was a part of the five-year Montezuma Well pasture restoration project, which was funded through the Arizona Water Protection Fund and is a cooperative venture between Natural Channel Design, Inc. and the National Park Service. The purposes of this project are to:

- restore and enhance riparian vegetation/habitats by removing invasive weedy species and replacing them with native species along the flood terrace of Wet Beaver Creek;
- reconnect the riparian habitats that are created by Wet Beaver Creek and the irrigation ditch;
- restore and enhance the declining riparian desert bosque and grassland habitats, and
- provide educational opportunities for Monument visitors regarding the importance of riparian plant communities and their habitats.

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Figure 64. NPS Press Release

2011 Public Outreach

A workshop was held at Montezuma Well on Saturday, February 19, 2011 by Allen Haden of NCD and Dennis Casper of NPS. A copy of the announcement is shown in Figure 65 . Due to stormy weather, only 10 people turned out to hear about and participate in the latest efforts in revegetation and installation of the associated irrigation system. Rodney Held of the Arizona Water Protection Fund was in attendance.

National Park Service
U.S. DEPARTMENT OF THE INTERIOR

Montezuma Castle and Tuzigoot
National Monuments
POB 219
Camp Verde, AZ 86322
928-567-5276
fax 928-567-3597

National Park Service News Release

FOR IMMEDIATE RELEASE – JANUARY 31, 2011
ED CUMMINS, CHIEF RANGER, MOCA/TUZI, 928-567-3322 X227

Public Workshop About Restoring Native Plants at Montezuma Well

The National Park Service, Natural Channel Design, Inc, a natural resource engineering firm in Flagstaff, and the Arizona Water Protection Fund, have been partnering to restore the Pasture area at Montezuma Well, a unit of Montezuma Castle National Monument. We will be hosting a free workshop on restoration practices being used in this project on Saturday, February 19th 2011. The workshop will include a field tour of the project area and an opportunity for "hands on" participation in the restoration process. Please come prepared to participate in the fun; hat, gloves, sunscreen, drinking water and snacks/lunch are recommended, and if you have a favorite shovel or planting spade, please bring it along. Meet at 9:00 AM by the picnic area at Montezuma Well. The walking tour begins at 9:30, and the workshop will wrap up around 2:00 p.m. There is no charge to participate in either the tour or the workshop.

Over 1200 seedlings will be planted during the week leading up to and including the workshop. This is the second year of extensive plantings for the 40 acres of the Pasture Restoration area for Montezuma Well. Last year, as part of the Pasture project, over 890 seedlings were planted with assistance from several local schools and many volunteers. 80% of those seedlings have survived.

The objectives of the Pasture Restoration project are to remove exotic invasive plants, restore native plant communities, and rehabilitate the degraded flood terrace habitat. The project area includes an active flood terrace along the northern border of Wet Beaver Creek, a tributary to the Verde River. The mesquite bosque, grassland, and riparian habitats in the area that are typical of flood terraces, are declining due to damage from decades of past ranching and farming activities that took place in the Pasture. The project's goals are to increase plant species diversity, and to improve both wildlife habitat and water quality by reducing erosion and sediment carried into Wet Beaver Creek during storm events.

Montezuma Well is located in the community of Rimrock, just north of Camp Verde and about 4 miles off of I-17. Take the I-17 exit #293 and follow the signs.

If you have questions or comments on the workshop or the project please contact either Dennis Casper, NPS Ecologist, (dennis_casper@nps.gov) or Allen Haden, Natural Channel Design, Inc. (allen@naturalchanneldesign.com).

Figure 65. Copy of the February 2011 workshop announcement

Prior to the workshop, students and teachers from Camp Verde and Mingus Union high schools came out on Wednesday, February 16, 2011 to participate in the revegetation efforts. The holes for the plants were drilled prior to their arrival and two representatives from NCD and three NPS staff were on hand to coordinate their efforts and explain to them the goals of the project and demonstrate proper planting techniques (Figure 66). Thirty-six students along with six adults participated in this re-vegetation effort.

Figure 66. Student volunteers planting containerized plants

2012 Public Outreach

Once again in 2012, volunteer groups were recruited to assist in the implementation of the project. For this effort, volunteer groups included the Student Conservation Organization, and Coconino Rural Environment Corps Youth Conservation Corps (CREC- YCC), The Nature Conservancy Leaders for Environmental Action in the Future (TNC-LEAF), and Camp Verde High School. The volunteers assisted with mechanical weed management including mowing and cutting of weeds that grew between herbicide spraying. In addition, volunteers helped to create distribution channels at the terminus of both the west field ditch and the pollinator garden ditch, which increased the flood irrigated watered area.

Local high school volunteers also participated in the growing and planting of sacaton plugs. Seeds were grown out at the local high school to plug size. These were then planted throughout the project area later in the year.

2013 Public Outreach

In May 2013, Allen Haden of NCD provided a talk on the Montezuma Well pasture restoration project to the Arizona Floodplain Managers Association meeting in Sedona, Arizona. After the talk a guided, walking tour of the site was provided to approximately 40 attendees by Allen Haden and Dennis Casper of the NPS. The project goals methods and monitoring was discussed as well as problems encountered and overcome during the implementation and planning process.

The final component of the public outreach is the creation and installation of interpretative signage along a trail that runs through the project area. A total of seven signs were created: one trailhead sign (24”wide x36” tall) was installed at the picnic area (Figure 67). The other six interpretive signs (36” wide x 24” tall) were installed at various stations around the trail (see Figure 68 for signage locations).

NCD collaborated with National Park Service interpretive staff to determine the location and information displayed on each sign. The signs were manufactured by iZone Imaging to NPS Standards. See Appendix A for photos proofs of all signage.

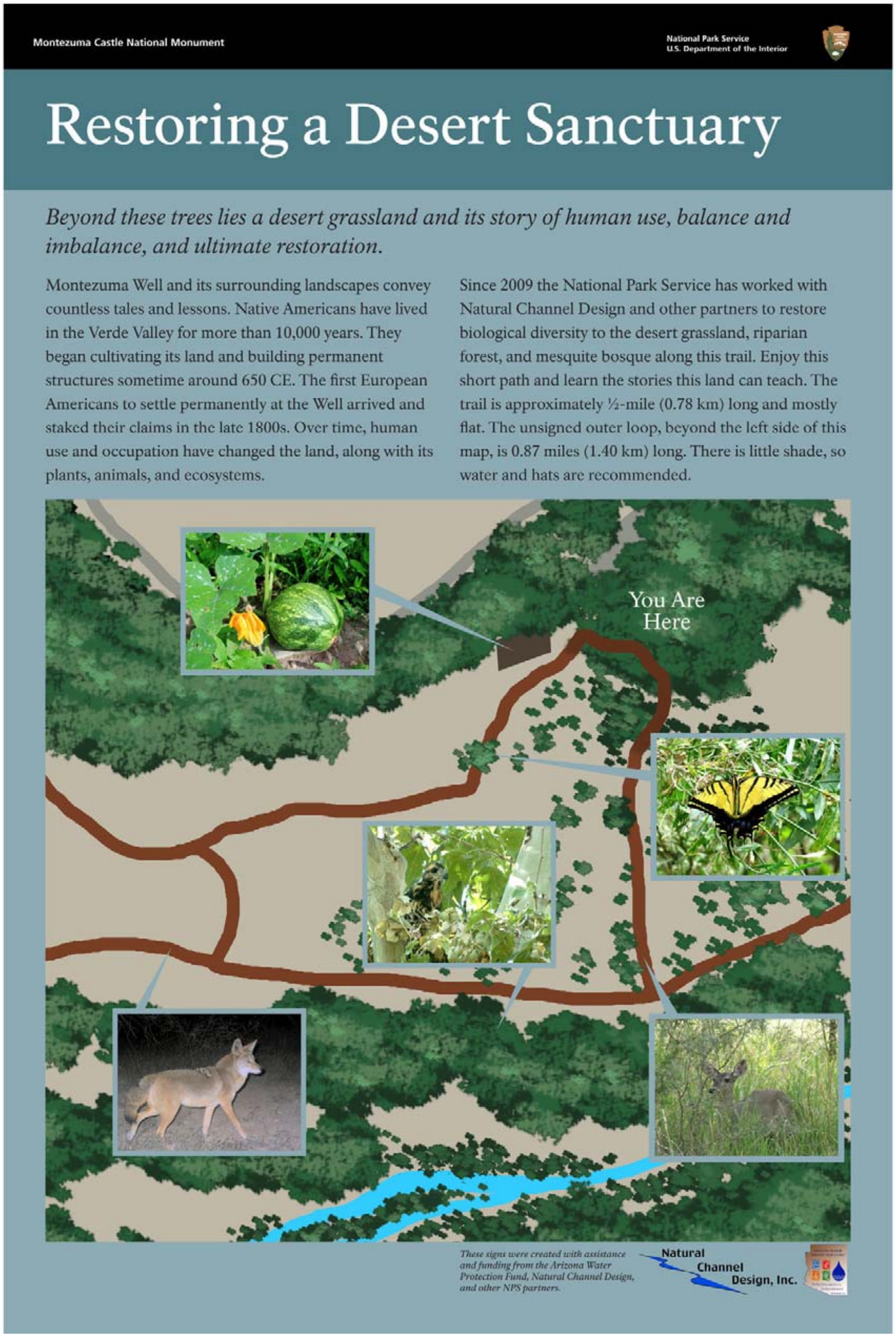


Figure 67. Trailhead sign

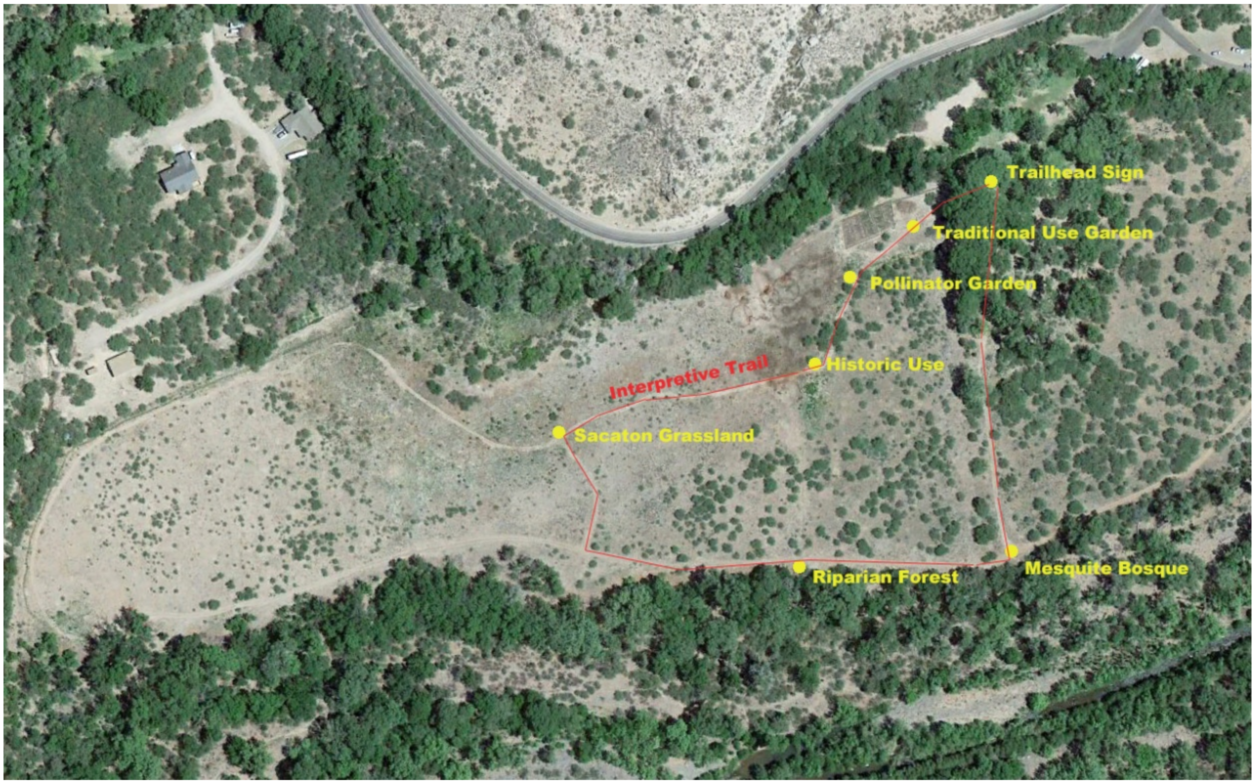


Figure 68. Interpretive trail with sign locations.

LESSONS LEARNED

Restoration of the mesquite bosque habitat at Montezuma's Well provides a great insight into the problems encountered with restoration of neglected agricultural land. Disturbance disrupted the soils and plant communities of the site and created an opening for non-native weed species to aggressively outcompete the remaining native species. Efforts by the NPS to address the weed issues were relatively unsuccessful without the funding to reestablish appropriate native plants. Funding by AWPF provided an opportunity to approach the project in a holistic manner and the results indicate that the site is trending towards the desired state.

The two main challenges to the restoration were the temporary irrigation system and the diverse, well established nonnative vegetation at the site.

Irrigation - The utilization of the existing, historical ditch to convey deeded water to the project reduced the expense of the project and made establishment of the new vegetation a viable proposition. However, the ongoing maintenance of the ditch, beyond the initial investment made by the grant proved problematic. Breaks to the ditch had to be repaired within the framework of the historical nature of the ditch and within the NPS management guidelines. Consequently, there were periods when the ditch did not provide adequate water to supply the irrigation system.

The use of micro irrigation allowed for irrigation of a large amount of acreage within the confines of the NPS water right. Additionally, the targeted use of the micro irrigation helped to manage against weed species by limiting the optimally wet ground to the vicinity. In areas where flood irrigation was utilized, control of species like Johnson grass was much harder. However, the large scale use of micro irrigation in combination with water quality issues greatly increased the manhours required to run and maintain the irrigation system. While many of the problems were anticipated in the design of the system, the amount of maintenance required to repair leaks and clogged emitters was beyond anticipated budget and likely led to some plants not getting timely doses of irrigation water. Low rainfall during the first years of plant establishment and irregular functioning of some emitters likely increased the mortality rate for the plants. The use of micro irrigation provided the project with many benefits, however the cost and commitment to run the system over several years was greater than anticipated and should be considered for future installations.

Weed management - The diverse and widespread weed community in the pastures provided a complex weed management issue. Dominant species would be targeted and controlled, only to have a subdominant species take advantage of the release and become the new problem. This was complicated by changes in soil moisture which can favor one species over another. Fortunately, the on-site NPS staff were incredibly knowledgeable and vigilant in documenting new weed outbreaks. NCD worked closely with staff to continually refine the types of herbicides used, the timing of application and the use of other management tools to counter new species outbreaks. Some important management tools (mowing especially) were limited once irrigation lines were installed and more labor intensive hand crews had to be organized and put on the ground to augment the herbicide treatments. Deep-rooted, perennial silverleaf nightshade proved tolerant to most herbicides and mowing. The weed management activities have increased its numbers except where heavy growth of native grasses has shaded out new growth. Areas with heavy infestations of this plant might warrant pre restoration treatments like tillage or other treatments to eliminate this species prior to planting with native plants.

APPENDIX A: PUBLIC OUTREACH SIGNAGE

Montezuma Castle National Monument

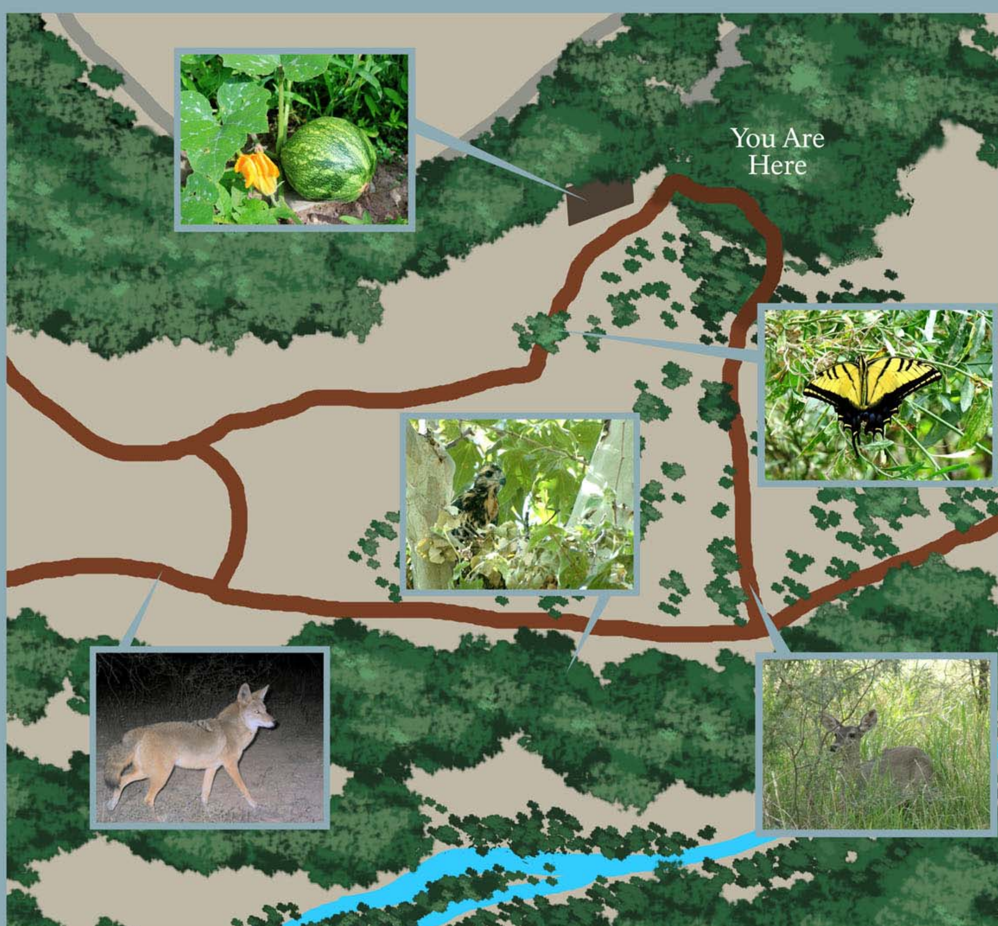
National Park Service
U.S. Department of the Interior

Restoring a Desert Sanctuary

Beyond these trees lies a desert grassland and its story of human use, balance and imbalance, and ultimate restoration.

Montezuma Well and its surrounding landscapes convey countless tales and lessons. Native Americans have lived in the Verde Valley for more than 10,000 years. They began cultivating its land and building permanent structures sometime around 650 CE. The first European Americans to settle permanently at the Well arrived and staked their claims in the late 1800s. Over time, human use and occupation have changed the land, along with its plants, animals, and ecosystems.

Since 2009 the National Park Service has worked with Natural Channel Design and other partners to restore biological diversity to the desert grassland, riparian forest, and mesquite bosque along this trail. Enjoy this short path and learn the stories this land can teach. The trail is approximately ½-mile (0.78 km) long and mostly flat. The unsigned outer loop, beyond the left side of this map, is 0.87 miles (1.40 km) long. There is little shade, so water and hats are recommended.



These signs were created with assistance and funding from the Arizona Water Protection Fund, Natural Channel Design, and other NPS partners.

Natural Channel Design, Inc.

Montezuma Castle National Monument

National Park Service
U.S. Department of the Interior

Making the Desert Bloom

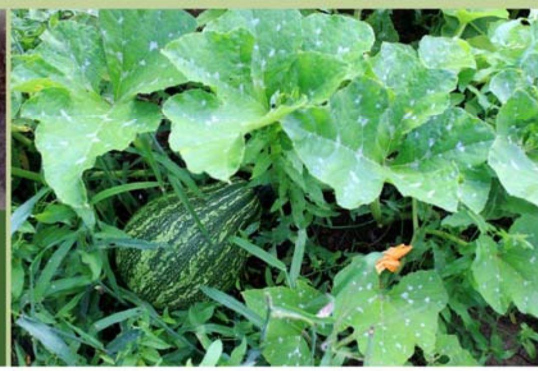
Central Arizona is a desert at first glance, but a closer inspection reveals life-giving water and an ideal environment for agriculture.

Humans have practiced agriculture in the Verde Valley for over 1,350 years, since long before the first pueblos were built here. Interacting with other cultures, the ancient peoples of central Arizona learned to plant, irrigate, and nurture seedlings on a landscape that hardly seems suitable for it.

In reality, the Verde Valley has more water than one might guess. Nestled between the Black Hills and the Colorado Plateau, the valley receives runoff from the east, west, and north. The Verde River is fed by seven major tributaries, and Montezuma Well supplies the valley with even more water—over 1.5 million gallons (5,678 kl) every day.

With this water and seasonal precipitation, prehistoric people made the desert bloom. Corn, beans, and squash grew alongside amaranth and other crops. Today, this garden is tended by Friends of the Well with assistance from Hopi Traditional Cultural Leaders, descendants of some of the people who farmed here so long ago.

Like a giant basin, the Verde Valley receives runoff from highlands in all directions. The largest tributaries flow from the edge of the immense Colorado Plateau to the northeast.



Prehistoric farmers grew corn, beans, squash, and cotton not far from where you are standing right now. Agriculture allowed people to settle in permanent villages and focus on interests other than finding their next meal. The people here used cotton to make some of the finest textiles anywhere in the Southwest.

Montezuma Castle National Monument

National Park Service
U.S. Department of the Interior

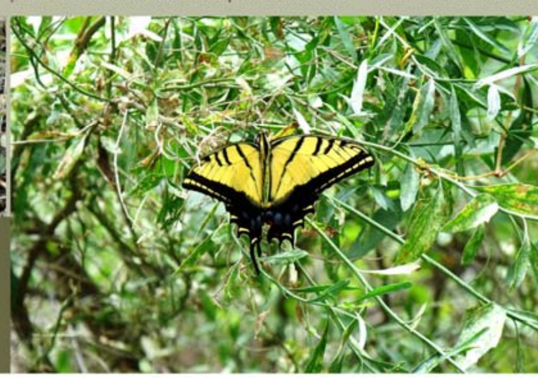
Relying on One Another

"When we try to pick out anything by itself, we find it hitched to everything else in the Universe." —John Muir

Nature is made up of astonishingly intricate, balanced systems. Animals inhale oxygen and exhale carbon dioxide, while plants use carbon dioxide to make energy and release oxygen as a by-product. Wildfires periodically scorch the landscape, but afterward, seedlings that have long awaited fire finally grow.

The plants here may appear random, but you are standing in the midst of prime pollinator habitat. Plants have evolved showy flowers and sweet nectar to attract insects and other creatures. Desert willow trees burst into fragrant, orchid-like blossoms in late spring that attract bees, hummingbirds, and songbirds. Succulent banana yuccas underneath attract nocturnal pronuba moths that venture deep into the yuccas' milky white flowers to lay eggs. Beargrass, desert verbena, and four o'clocks attract moths and butterflies by the dozens. The animals that come to these plants will also visit others of the same species nearby. As these birds, bees, bugs, and bats move from plant to plant, they will carry the pollen with them and ensure the dawn of the next generation.

White-lined sphinx moths and two-tailed tiger swallowtails are among the many kinds of creatures that have adapted mutually beneficial relationships with plants. The plants provide nourishment and nest space, while the animals help the plants reproduce.



In late spring and early summer, banana yuccas raise a bouquet of brilliant blooms to attract pollinators from afar. The unmistakeable sight and fragrant scent help ensure that this individual will pass its genes to future plants.

Montezuma Castle National Monument

National Park Service
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Harbingers of Change

"... after marching six leagues we reached a cienaguilla which flows into a small water ditch and we came to an abandoned pueblo." —Diego Pérez de Luxán, 1583

The first Europeans to visit Montezuma Well were probably Spanish explorers. An expedition led by Antonio Espejo entered the Verde Valley in search of gold in 1583. The prehistoric Puebloans who lived at the Well had already departed more than 100 years prior, but expedition journals indicate the Spanish may have found the remains of their ancient homes, as well as Yavapai still living nearby.

By the late 1800s, the first Americans of European descent began making permanent claims to the land surrounding the Well. Wales Arnold started one of the first nearby ranches. Sam Shull sold his ranch at the Well to Abraham Smith for forty dollars, a pair of chaps, and a horse. Smith doubled his investment when he sold the land to William B. Back in 1888—for *two* horses. Back's son, William L. Back, later inherited the ranch and became the first person to promote the Well to tourists in the early 1900s.

European and United States explorers and pioneers heralded transformation throughout the west. Their arrival foreshadowed colossal changes to people, cultures, ways of life, and the land itself.

We can only imagine what the first Spanish explorers thought when they stumbled upon Montezuma Well in 1583. By 1953, 370 years later, this pasture had taken shape. The modern picnic area where you began your hike is located in the grove of trees at the right of the larger image.

Montezuma Castle National Monument

National Park Service
U.S. Department of the Interior

Damage and Renewal

People—prehistoric, historic, and modern—have always affected the land and its biodiversity. Today, park scientists work to rehabilitate the damaged desert grassland.

Human occupation of the Verde Valley greatly altered the land by the 1900s. Cattle grazed selectively, nibbling the tastiest morsels and leaving behind plants that were poisonous or prickly. Over time, some plant species diminished severely, while others grew quickly to fill in gaps they left behind. Invasive plants like Russian thistle, Mexican fireweed, London rocket, and silverleaf nightshade quickly took over, reducing the plant diversity of this former desert grassland. As plant species changed, so did the animals that relied on them. Small creatures dependent on grass seeds diminished in population, affecting their predators and the entire web of life.

Since 2009, the National Park Service has worked with Natural Channel Design and other partners to restore balance to this damaged ecosystem. Here, the desert grassland is slowly making a comeback. Large clumps of native sacatón and other grasses have replaced nightshade and thistle.

The flower of the silverleaf nightshade may be one of the Verde Valley's loveliest. However, it is poisonous, and grazing cattle avoid it. The plant quickly grows out of control and takes over large swaths of disturbed land like the area around this mesquite tree.

Watch carefully, and you may see a family group of javelinas trotting through the restored vegetation.

Montezuma Castle National Monument

National Park Service
U.S. Department of the Interior

Ribbon of Water

"Water is the driver of Nature." —Leonardo da Vinci

Surface water is vitally important in the Arizona desert. The forest before you rises along the banks of Wet Beaver Creek, beginning in the canyon country of the Mogollon Rim, just a few miles northeast. It flows past Montezuma Well, joins Dry Beaver Creek, and continues beyond Montezuma Castle and into the Verde River. Everywhere along its banks, the desert blossoms.

Here in this riparian environment, the short, ephemeral grasses and scrubby vegetation give way to a verdant riverine community of Fremont cottonwood, velvet ash, and Arizona sycamore. Supplied year-round with ample water, plants grow large, broad leaves to take full advantage of the spring and summer sun.

The riparian forest is a haven for animal life, as well. Deer find sanctuary in the shade. Striped and hog-nosed skunks root through leaf litter in search of bugs, grubs, and scorpions. Hawks, woodpeckers, warblers, and flycatchers inhabit the branches above. The animals leave many signs of their passing for the observant. Look carefully in the mud along the trail and see what may have left its tracks.

Surface water supports people and wildlife, from large deer and coyotes all the way to tiny insects. Damselflies grow up in the water. As adults, these beneficial insects eat large numbers of mosquitoes and flies, lowering pest populations.

In the presence of water, desert scrub gives way to giants. Away from the creek, plants have evolved small sizes and tiny leaves that help them save water and use it efficiently. Here, water is plentiful, and everything grows larger. However, there is a trade-off: if the water disappears, the large sycamores, cottonwoods, and ash trees will die.

Large feline tracks with no visible claw marks indicate the passage of a mountain lion or cougar after a desert rain.

Montezuma Castle National Monument

National Park Service
U.S. Department of the Interior

Desert Survivors

The mesquite tree has evolved some astonishing methods for persevering in a land where water is scarce. Even so, this incredible plant is in peril.

In the creek's floodplain, plants have adapted to survive with limited surface water. Rain is infrequent here, with less than 12 inches (30 cm) of precipitation in an entire year. Most of what does come falls in short bursts and runs off quickly. Mesquite trees have mastered the art of capturing it.

In order to quickly take advantage of rainfall, each mesquite spreads out a network of shallow roots up to 100 feet (30.5 m) across. For dryer times each tree grows a taproot up to 150 feet (45.7 m) deep to seek subterranean groundwater. Tiny leaves help the trees conserve what they find. Enough water is present that an entire mesquite forest, called a *bosque*, has developed here.

Mesquite bosques are excellent wildlife habitat. The shade and cover attract deer, javelinas, and quail. However, mesquites face significant threats. Pumping of groundwater for human use has lowered water tables throughout Arizona, sometimes even beyond the mesquite's profound reach. Entire bosques have died in parts of the state, and they now cover only a fraction of their original territory.

Mesquite trees have evolved impressive root systems to make the most of fleeting rainfall. Widely spread roots near the surface capture water there before it can evaporate, while deep taproots penetrate the earth in search of groundwater.

Though mesquite trees are consummate survivors, they are threatened by depleted groundwater. Falling water tables can leave behind dead skeletons where healthy mesquite bosques once stood.

Linger awhile, watch, and listen, and the desert's denizens may come out. Gambel's quail travel in small flocks, often walking. Males keep a wary eye on their surroundings while the rest of the flock forages.

APPENDIX B: DESIGN CONSTRUCTION SHEETS

APPENDIX C: AS-BUILT CONSTRUCTION SHEETS