HORSESHOE RESERVOIR HABITAT RESTORATION STUDY

Final Report Prepared for the Salt River Project and The Nature Conservancy
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Prepared by
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HORSESHOE RESERVOIR HABITAT RESTORATION STUDY

Tice Supplee (National Audubon Society) and Mark Briggs (New River/New World Consulting)

Final Report to Salt River Project
DRAFT
September 30, 2022

INTRODUCTION

During the summer and fall of 2021 the US Bureau of Reclamation in partnership with SRP conducted the Verde Reservoirs Sediment Mitigation Study (VRSMS). The objective of the study was to evaluate alternatives to restore capacity lost at Horseshoe Reservoir to protect water supply resiliency and adapt facilities and operations for expected future conditions resulting from climate change (VRSMS 2021). The modification of Verde River storage options under the two alternatives that raise the height of Bartlett Dam offer operational flexibility at Horseshoe Reservoir not currently available. Under the Bartlett Modification 1 and 2 alternatives, Horseshoe Reservoir would be operated in a run-of-river operational regime that does not use Horseshoe Reservoir as a conservation pool but matches inflows to outflows when possible.

This operational change offers opportunities for ecological enhancements within the current footprint of Horseshoe Reservoir. The central objective of this study and report is to provide SRP input on location and type of native plant habitat that potentially can be established in the Horseshoe Dam reservoir study area above and beyond any compensatory mitigation requirements if Horseshoe Reservoir is managed under a run-of-river operational regime. In support of realizing the central objective, supporting study objectives include a review of literature and anecdotal experiences of past reservoir and river bottomland restoration, restoration tactics, and methods for controlling non-native species. To realize the above objectives, this report is organized as follows:

Section One   Study Methods and Overview of Horseshoe Reservoir and the Verde River Watershed

Section Two   Lessons Learned from Past Reservoir Restoration Efforts

Section Three   Central Challenges to Establishing Native Plant Communities within Horseshoe Reservoir

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SECTION ONE
STUDY METHODS AND OVERVIEW OF HORSESHOE RESERVOIR
AND THE VERDE RIVER WATERSHED

METHODS

For this phase of the Horseshoe Reservoir restoration study, methods entailed conducting field reconnaissance, a review of literature, an assessment of available ground and aerial photography, and taking advantage of data and information organized and provided by SRP.

Two field reconnaissance trips were conducted of the study area. One during November 2021 and the second during April 2022. The November 2021 trip took place prior to the grant award and focused on learning from SRP about reservoir operations and management and exploring the geography in and around Horseshoe Dam, itself, and the southern portions of the eastern reservoir shoreline. A USFS hydrologist also participated, providing valuable insights about the drainages and restoration considerations. We discussed the importance of sampling soils at potential restoration sites and understanding the depth to groundwater. This trip was particularly important to understanding the upland vegetation community that surrounds much of the reservoir, which consists of comparatively sparse Sonoran Desert plant species such as mesquite (*Prosopis* spp.), palo verde (*Parkinsonia* spp.), brittlebush (*Encelia farinosa*), creosote bush (*Larrea tridentata*), amongst many others. Such desert plants may be appropriate to establish below the current conservation pool water line.

The April visit was carried out in two days. The first day was via kayaks and explored the Verde River bottomland environment downstream of Sheepshead bridge, including much of the northern portion of Horseshoe Reservoir upstream of the mouth of Lime Creek. Day One included personnel from SRP, Bureau of Reclamation, TNC and others, with the thematic aim to understand current biophysical conditions of the river's bottomland environment as well as to learn about a study being led by Reclamation that is focusing on the river's razorback sucker (*Xyrauchen texanus*) population. The results of this study will be valuable to not only learning about the movement of the razorback sucker along the Verde River, including within the reservoir, but also how we ultimately can incorporate parts of the razorback study into the recommendations for restoring bottomland plant communities in Horseshoe Reservoir. The focus of the second day of the April visit was on the reservoir bottomland environment surrounding the mouths of Deadman Wash and Lime Creek. In addition to other benefits, these trips provided the opportunity to discuss potential restoration options for Horseshoe Reservoir with a diverse team of hydrologists, biologists, managers, and other natural resource experts.

Review of the literature focused on identifying books, articles and narratives that described riparian vegetation conditions and restoration actions that focused on reservoirs and lakes. The vast majority of the available literature focuses on the impacts of dams and associated water operations on downstream bottomland biophysical conditions, with many studies evaluating the inundation timing and duration of impounded waters, desiccation, water quality, soils, topography and slope as key elements that affect the establishment of riparian vegetation. Case studies associated with reservoir investigations and/or restoration actions that took place in climates and geographies similar to central Arizona were identified and summarized as a means to providing key lessons learned that may be valuable as SRP moves forward with subsequent

phases of restoration. Roosevelt Lake in Arizona and Elephant Butte reservoir in New Mexico were identified as part of this review and will be presented in greater detail in the final version of this report after these two sites are visited by the greater Horseshoe Reservoir restoration team during the Fall of 2022.

SRP's Cartographic & GIS Services Department organized, published, and made readily available a variety of aerial photographs and other remote sensing information of the Horseshoe Reservoir study area for the years of 2002-2021. Such was instrumental to understanding the inundation frequency, and changes in bottomland vegetation and morphologic conditions over the last two decades in key parts of the Horseshoe Reservoir study area (e.g., sites identified as having high potential for bringing back native bottomland plant communities). For example, an analysis of multispectral and LiDar data from 2002, 2012, and 2021 was essential to understanding changes in reservoir morphology as well as the timing and extent of bottomland plant establishment.

OVERVIEW OF HORSESHOE RESERVOIR AND THE VERDE RIVER WATERSHED

The Verde Watershed encompasses 17,198 sq kilometers (6,640 square miles) in central Arizona, overlapping the counties of Yavapai, Coconino, Gila, and Maricopa, with about 72% of its land area under public management (mostly U.S. Forest Service). The Verde River watershed is a significant source of water supply for the state of Arizona, helping in particular to meet the water demands of the greater Phoenix Area (Arizona's capital and largest city). Other major cities in the watershed include Prescott, Cottonwood, Clarkdale, Payson, Sedona, and Camp Verde.

The Verde River watershed is part of the Mogollon Highlands Ecoregion, flowing through the highlands and valleys of central Arizona that are characterized by transitional regional physiography and geology between the high elevation, relatively flat Colorado Plateau and the lower elevation Basin and Range province (Pearthree 1996). The watershed is rich in natural beauty and cultural history, and encompasses a diversity of terrain, including upland plains, forested mountain ranges, broad desert valleys with accompanying broad alluvial floodplains with rich riparian ecosystems interspersed by narrow canyons.

Given that the grand majority of the Verde River is free flowing (i.e., the entire watershed upstream of Horseshoe Dam), it is not a coincidence that the river is home to one of the largest remaining native Fremont cottonwood and Goodding's willow mixed broadleaf riparian forests. The river, along with surrounding upland habitat, supports 10 threatened and endangered species, and many more migrating and resident species. Forty and a half miles of the Verde River and 16.8 miles of Fossil Creek are federally designated as wild, scenic, or recreational[1]. The wild and

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[1] The northern boundary of the Scenic River designation for the Verde River is the section line between Section 26 and 27, T13N, R5E, Gila-Salt River meridian. The southern boundary is adjacent to the Mazatzal Wilderness, which is within Section 11, T11N, R6E. The northern boundary of the Wild River Area is the boundary of the Mazatzal Wilderness which is within Section 11, T11N, R6E, with the southern boundary located at the confluence of Red Creek within Section 34, T9 l/2N, R6E. In total, the Wild River designation is 35.7 kilometers (22.2 miles) from the

scenic designation of the Lower Verde stretches from below Beasley Flat and Camp Verde to the Horseshoe dam reservoir. The Prescott and Coconino National Forests are seeking an additional 37 miles of the Upper Verde River as eligible for inclusion in the National Wild and Scenic Rivers System, with the final step in the process being a suitability study that will allow the area to be evaluated as a potentially worthy addition to the National Wild and Scenic Rivers System. In addition to federal wild and scenic designation, Oak Creek, West Fork Oak Creek, and Fossil Creek are designated Outstanding Waters by the state of Arizona

The National Audubon Society has recognized Important Bird Areas (IBA) on the Verde River and some tributaries that are of very high value for native birds. The IBAs are located on the upper Verde River from Stillman Lake to the USFS boundary (Upper Verde River State Wildlife Area IBA), the middle Verde River from Tuzgoot National Monument to the downstream boundary of the Verde River Greenway (Tuzigoot IBA), lower Oak Creek below the town of Sedona to Cornville (Lower Oak Creek IBA), the middle Verde River from upstream of Interstate 17 through the town of Camp Verde, including the tributary East Clear Creek (Camp Verde IBA), the lower Verde River from Beasley Flat to the confluence with the Salt River below Bartlett Dam and the Fossil Creek tributary (Salt and Verde Riparian Ecosystem IBA). Descriptions of these Important Bird Areas can be found at http://aziba.org

The Verde River corridor is also a recognized eco-tourism destination, with fishing, rafting, hiking, and bird and wildlife-watching opportunities, providing important revenue to the Verde Valley's rural economy. Although much of Arizona's forecasted population boom will occur in the emerging Phoenix/Tucson megalopolis, the state's rural areas are also rapidly developing (Bolin et al. 2008). Communities of Arizona's Central Highlands are part of an expanding environmental amenity economy, where agriculture, ranching, and mining are being superseded by housing construction, retail sales, and tourism (Collins and Bolin, 2007; Sheridan, 1995). In part to address the potential negative impacts of land use change and population growth in the Verde River watershed on the Verde River, active and effective conservation coalitions have been established in the watershed that include the US Forest Service, The Nature Conservancy, Friends of the Verde River, Salt River Project (SRP), amongst other groups and citizens, working collaboratively to protect native species and local economies and cultures.

As defined by the U.S. Geological Service and U.S. EPA, the Verde River watershed is divided into three surface water sub-basins (https://maps.waterdata.usgs.gov): 1) the Big Chino-Williamson Valley at the headwaters of the river; 2) the Middle Verde running through the Verde Valley and the communities of Clarkdale, Cottonwood, and Camp Verde; and 3) the Lower Verde, extending downstream of Camp Verde to the river's confluence with the Salt River (Fig. 1). Horseshoe Reservoir, as well as Bartlett Reservoir, are located in the central portion of the Lower Verde.

Scenic portion is 29.5 kilometers (18.3 miles), for a total of 65.2 kilometers (40.5 miles) [see https://www.rivers.gov/rivers/verde.php]
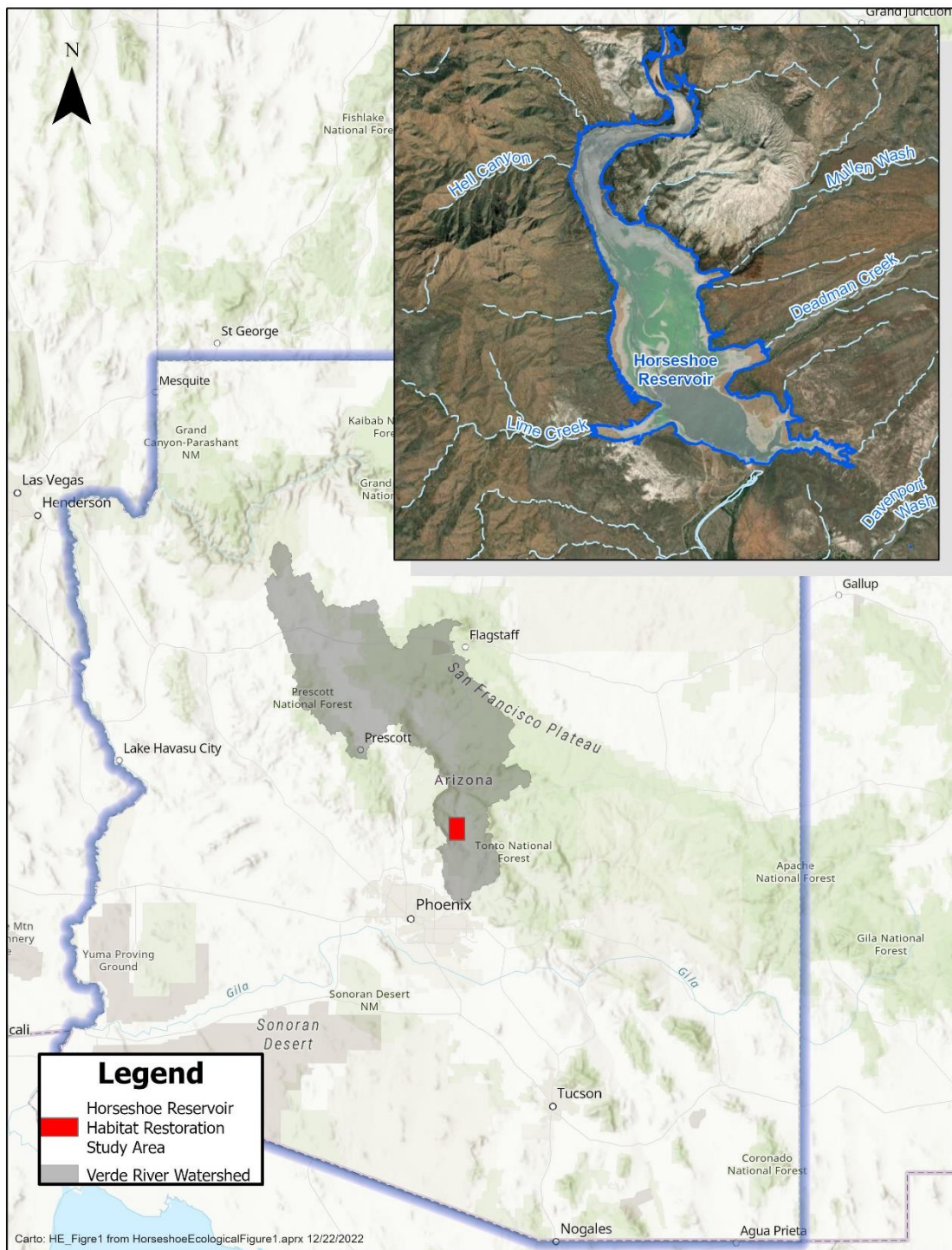
Figure 1. Place map showing location of Horseshoe Reservoir (red square in the map of Arizona) and aerial image of Horseshoe Reservoir with selected geographic features labeled (upper right) (images courtesy of SRP Cartographic & GIS Services).

The upper parts of the Verde River watershed receive an annual average of about 20 inches of rain and 3 inches of snow.[2] The Upper and Middle Verde Watersheds overlay the Big Chino and Little Chino aquifers, which are two of the main sources of groundwater supply in the watershed and contribute significant volumes of flow to the Upper Verde River (Wirt 2005). Water input from these aquifers emerge in three locations in the vicinity of the confluence of Granite Creek and the Verde River, including (a) Stillman Lake (impounded section of the Verde River channel between river miles 1.0 and 2.0, (b) the cienega in lower Granite Creek, which is often referred to as "Lower Granite spring," and (c) the gaining reach of the Verde River channel downstream from river mile two (Wirt 2005). A report by Arizona Department of Environmental Quality (ADEQ) summarizing the water resources of the state, mapped 724 km (450 miles) of perennial streams in the Verde River basin, 3,404 km (2,115 miles) of intermittent streams, and 9,640 km (5,990 miles) of ephemeral. In addition, the same assessment mapped 1,863 ha (4,603 acres) of perennial lakes (including Horseshoe and Bartlett Reservoirs) and 1,471 ha (3,636 acres) of non-perennial lakes. (see https://legacy.azdeq.gov/environ/water/assessment/download/vrw.pdf)

Perennial flow along the Verde River 'mainstem' originates east of Paulden from a series of springs in the remote and rugged upper canyons below Sullivan Lake that are fed by interconnected aquifers in the Big Chino basin. Most of the first 35 km (22 miles) of the Verde's base flow is dependent on these springs and the ephemeral tributaries of Granite, Big Creek Chino Wash, and Hell Canyon. Below Perkinsville the Verde is joined by additional springs and Sycamore Canyon. Below Camp Verde perennial tributaries that include Oak Creek, Wet Beaver Creek, West Clear Creek, Fossil Creek, and East Verde River.

The reach of interest for this report is downstream of Camp Verde. The Verde River is entrenched into a relatively narrow, deep canyon that extends to just upstream of Horseshoe Reservoir, where the valley bottom widens, and the river is less confined. The entrenchment of the Verde River in this reach is due to downcutting through blocked basin outlets that began about 2 to 2.5 million years ago and has continued through the Quaternary (Pope and Péwé, 1973; Pope, 1974; Péwé, 1978, Pearthree, 1993; House and Pearthree, 1993).

The long period of downcutting by the Verde River has created a series of terraces that flank the river ranging in age from early-Pleistocene to late Holocene. In general, the older terraces are more erosion-resistant than the younger terraces (Pearthree 1996). Long-term downcutting and the relative erodibility of pre-Quaternary bedrock and basin-fill units effectively control the extent and character of the Quaternary alluvial deposits and floodplain along the Verde River. Where the lithologies are more erosion-resistant, the river valley is steep and narrow with relatively limited amounts of alluvial storage in the valley bottom. In contrast, where the bounding lithologies are more erodible, the valley width is greater, the slope is reduced, and there is considerably more valley alluvial storage (Pearthree 1996). As with most canyon-bound rivers, local valley constrictions and expansions affect the extent and duration of alluvial sediment storage and evacuation (Graf, 1980; Webb et al., 1988; Lisle, 1986; O'Connor et al., 1986; Harvey et al., 1993).

The relative widths of the valley floor determine the extent that large infrequent flood events (e.g., floods with magnitudes >10-year recurrence interval that tend to control channel form in

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[2] https://legacy.azdeq.gov/environ/water/assessment/download/vrw.pdf

arid regions (Baker, 1977; Wolman and Gerson, 1978; Graf, 1988)) distribute alluvium and alter channel form. In confined reaches of the valley, there is little potential for lateral migration of the river, with the potential for lateral migration increasing substantially where the valley is wider. In general, where the valleys are narrow and confined, the boom and bust hydrology typical of many streams in arid regions foments dramatic and frequent changes in sediment movement, storage and evacuation, with consequential changes in channel and floodplain conditions that can eliminate or modify riparian vegetation that may have established during inter flood periods. In contrast, wider reaches tend to be depositional during infrequent flood events, providing ideal conditions for the establishment and long-term presence of obligate riparian plant communities (like the *Populus* and *Salix* plant communities mentioned earlier). Considering this fact on its own merit underscores the potential for establishing native obligate riparian plants in Horseshoe Reservoir with pass through flow management.

HORSESHOE DAM AND RESERVOIR

Horseshoe Dam is an earth filled structure built by the Phelps-Dodge Copper Products Corporation for the Salt River Valley Water Users' Association under a water exchange agreement and is located on the Verde River about 93 km (58 miles) northeast of Phoenix. At the time construction of Horseshoe Dam was completed in 1946, the reservoir capacity behind Horseshoe Dam was 162.2×10^6 m^3 (131,500 acre-feet), but that capacity has been reduced by sediment infill from the Verde River system and now stands at 121.7×10^6 m^3 (98,656.5 acre-ft). The surface water elevation behind the dam at conservation pool is 617.5 m (2,026 ft). At that surface water elevation, the reservoir contains 121.7×10^6 m^3 (98,656.5 acre-ft) of water, is 23 m (76 feet) deep at its deepest point, has a water surface area of 1,054.4 ha (2,605.4 acres), and a shoreline of approximately 43.5 km (27 miles)[3]. Spillway gates were added to the dam in 1949 by the city of Phoenix to increase the domestic water supply. In 1952 the dam was raised 1.2 m (4 feet) to an elevation of 623 m (2,044 ft) (www.srpnet.com/; US Bureau of Reclamation).Horseshoe Dam was later modified by the U.S. Bureau of Reclamation in 1993 to address concerns about safety in the event of a Probable Maximum Flood or Maximum Credible Earthquake. Modifications included construction of a fuse plug auxiliary spillway with an erodible embankment and a concrete foundation 619 m (2,000 feet) west of the existing spillway. In addition, a 113,220 m^3 (148,000 cubic-yard) stability berm was constructed at the downstream toe of the dam to help stabilize it in the event of an earthquake, and the dam was raised eight feet to enable the spillway to pass the Probable Maximum Flood. To prevent overtopping of the structure from wave action, an additional parapet of just over a meter (about 4 feet) was built on the dam's crest. Other work included modifying the service spillway gates, and construction of an auxiliary spillway, closure dike and training dike. The dam tender facilities were also relocated and the road to the boat ramp upgraded. As a result of sediment from the Verde River settling in the reservoir, a 2012 preliminary survey showed that the reservoir's water storage capacity has been reduced by almost 56.7×10^6 m^3 (46,000 acre-feet) since its construction (VRSMS 2021).

The USGS gauge at Tangle Creek, whose confluence is over 15 km upstream of Horseshoe Dam, provides the most useful data for understanding Verde River streamflow into the reservoir. The

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[3] Summary data when Horseshoe Reservoir is at Conservation Pool provided by SRP.

flow record at Tangle Creek prior to 2005 is spotty, but is complete 2007 to date. Average flow from 2007 to 2021 is 11.3 m^3/sec (398.3 ft^3/sec) with average flow during March the greatest at 31.3 m^3/sec (1,104 ft^3/sec) and June at 2.5 m^3/sec (87.3 ft^3/sec) being the least. The extremes of boom and bust streamflow into Horseshoe Reservoir poses challenges to establishing desirable plant communities in the study area. More detail on these challenges will be presented in Section Three. One of the key challenges will be planting in sites where water availability is sufficient to allow artificially planted species to survive the hot, dry months of May and June. Average daily flow at Tangle Creek during these months is 3.1 m^3/sec (110.5 ft^3/sec) for the period of record from 2006 to date (with one standard deviation around the mean of 1 m^3/sec (36.7 ft^3/sec), ranging from a low of 1.3 m^3/sec (45.1 ft^3/sec) to a high mean daily average flow to 8.4 m^3/sec (296 ft^3/sec). A mean daily flow equal to or less than 2 m^3/sec (70 ft^3/sec) during the May to June months occurs 10.3% of the time; less than or equal to 2.8 m^3/sec (100 ft^3/sec) 46.4% of the time, and less than or equal to 4.2 (150 ft^3/sec) 86% of the time.[4]

The 'study area' of this report is the footprint of Horseshoe Reservoir at conservation pool, which is defined when the surface water elevation behind Horseshoe Dam reaches 618 m (2,026 ft). At that elevation, the pool behind Horseshoe Dam extends roughly 10.2 km (6.3 miles) upstream of the dam and occupies an area of approximately 9.5 square kilometers (3.7 sq miles). The Horseshoe Reservoir study area is widest in a general east – west direction at a point just upstream of the mouth of Lime Creek to the mouth of Deadman's Wash. At that location, the width of surface water at conservation pool extends over 1.5 km.

Three ephemeral tributaries enter the Verde River system at Horseshoe Reservoir. Lime Creek enters on the west side of Horseshoe Reservoir just upstream of Horseshoe Dam, while Mullen Creek and Deadman Wash enter the reservoir on the eastern shore of the reservoir. Of the three, Deadman Wash is the best documented with regard to basic physiography and hydrology information. Deadman Wash watershed occupies about 104 square kilometers (40.3 square miles), descending from a maximum elevation of 2,405 m (7,888 ft) to 618 m (2,026 ft) at its confluence with the Verde River. Not surprisingly, Deadman Wash, like Lime Creek and Mullen Creek, typify the boom-bust hydrology of many small Arizona streams with extensive periods of no-flow punctuated by brief periods of high magnitude discharge. Flow duration of more than several days only occurs with any reliable frequency during the winter months when precipitation frequently occurs for over a day via frontal storm systems. In addition, precipitation events of similar duration can occur in the early Fall when southern Arizona can be on the receiving end of remnant tropical cyclones. During the monsoon season, high magnitude flow of long duration from these tributaries is rare. High magnitude flows do occur during this time period, of course, but they do so abruptly only to disappear just as quickly.

A one-day, two-year maximum flow into Horseshoe Reservoir from Deadman Wash is estimated at 6.3 m^3/sec (224 ft^3/sec). This means that, on average, Deadman Wash experiences that discharge during one 24-hour period once every two years. In comparison, a seven-day, two year maximum is estimated at 1.7 m^3/sec (61.6 ft^3/sec) and a 15-day, two-year maximum is 1.2 m^3/sec (41 ft^3/sec). When they do occur, such flow events provide significant water volume. The aforementioned one day, two year maximum gives a volume of 0.55 x 10^6 m^3 (444 acre-ft), while the seven day, two year maximum produces 1.1 x 10^6 m^3 (855 acre-ft), and the 15-day,

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[4] Based on analysis of data collected at USGS streamflow gauge near Tangle Creek.

two-year maximum produces 1.5×10^6 m^3 (1,220 acre-ft). Not insignificant water from an ephemeral tributary, particularly given that the above water volume estimates reflect inputs only from Deadman's Wash. Lime Creek and Mullen Wash are also contributing, though Mullen Wash is much smaller in area than Lime Creek and Deadman's Wash. That noted, the flashy, episodic flow from ephemeral tributaries makes it difficult to reliably count on these contributions as sources of water for establishing desired bottomland plants, particularly during the hot, dry months prior to the monsoon when plant evapotranspiration rates (and, thus, water needs) are the highest.

SECTION TWO
LESSONS LEARNED FROM PAST RESERVOIR RESTORATION EFFORTS

INTRODUCTION

In this section, reservoir case studies from different parts of the world are summarized that may offer insights and lessons learned helpful to SRP's efforts to reestablish native bottomland habitat in Horseshoe Reservoir. The central criteria used to identify useful case studies are reservoir settings where water management and/or on-the-ground efforts aimed to protect and/or bring back native habitat. In addition to reservoirs, selected habitat restoration efforts in lake settings are also included in the list of case studies, below. Three points to make before reviewing the case studies.

First, identifying reservoirs in other geographies where efforts were or are being made to bring back native habitat has the potential to provide SRP a treasure trove of insights and lessons learned pertinent to establishing native bottomland habitat and species in Horseshoe Reservoir; insights and lessons that are likely not well-documented and may only be available via direct discussion with project personnel working in these other areas. In this context, it is important to emphasize that the grand majority of documented reservoir 'restoration' efforts are in mesic climates involving reservoirs that do not experience routine dramatic fluctuations in surface water elevation (at least relative to reservoirs in arid settings). In these settings, water quality issues and eutrophication, particularly from the standpoint of protecting water supplies, are what drive restoration actions (Cooke and Carlson 1989). For example, in their treatise on lake and reservoir management and restoration, Cooke et al. (2005), notes four main reasons why restoration actions are initiated: (i) to control problems caused by algae; (ii) control excessive macrophyte biomass; (iii) to alleviate oxygen problems; and (iv) remove sediment (Cooke et al. 2005). There are limited examples of intentional reservoir management that will promulgate native habitats.

Second, the identification of habitat restoration efforts taking place in other geographies was not originally emphasized as part of the work plan for this study. It was an 'add on' of sorts that stemmed from reviewing literature associated with reservoir restoration. As such, the list of case studies summarized below should not be considered exhaustive. If SRP finds such research useful, it is not only likely that additional case studies can be identified, but that additional pertinent information can be developed from the case studies that are presented, below. As alluded to above, a discussion with project personnel associated with a case study of interest to SRP could yield much useful information with little expenditure of time and cost.

Third, although the global pool of habitat restoration efforts taking place in reservoir settings appears to be relatively small, such efforts are likely to become more numerous in the near future. Approximately 70% of the world's rivers are intercepted by dams (Kummu and Varis, 2007). The last 60 years have seen the most rapid growth in the global active storage capacity of reservoirs from approximately 200 km^3 to over 5,000 km^3, which is over 70% of the total global reservoir capacity (Vorosmarty et al., 1997; Zhou et al., 2016). The point being that, although dam building has been with us for thousands of years, the great majority of the world's dams, and the reservoirs that have formed behind them, are relatively young. As reservoir and dam

infrastructure ages with consummate impacts on native species and people, the call for restoring habitat within reservoir settings (via the removal of dams, altering dam management, other) will become more of a priority as the group of relatively young reservoirs matures. Conducting habitat restoration at Horseshoe Reservoir presents an important opportunity to contribute to this exciting field of restoration, particularly if monitoring programs can be put in place that allow thoughtful quantification of habitat restoration results (see also, 'monitoring' in Section V).

CASE STUDIES

The reservoir 'restoration' case studies presented below have at least as one of their objectives to establish and/or protect native habitat and species. Restoration tactics employed to accomplish this objective involve conducting one or more of the following: native species reintroduction, controlling non-native species, changing water management and/or dam infrastructure, and earth moving, amongst other actions. Several of the case studies highlighted below are from geographies and climates distinctly different from central Arizona but were nonetheless identified as potential interest to SRP given the restoration process that was used and/or the methods and tools employed to gather data to address key knowledge gaps associated with developing restoration objectives and tactics. Case studies involving lake ecosystems are also included.

ARACADIA LAKE, OKLAHOMA

Arcadia Lake is located within the metropolitan area of Oklahoma City and Edmund, in Oklahoma County, Oklahoma, about 2.4 km (1.5 miles) southwest of Arcadia, Oklahoma. Construction of the earth-filled dam was authorized by the Flood Control Act of 1970 and approved for construction by the Secretary of the Army for the purposes of flood control, water supply, and recreation. Construction was completed in 1986, and conservation pool was reached in 1989. Background information on this restoration effort is summarized in Dick et al. (2004).

The dam impounds a section of the Deep Fork River, with drainage coming principally from surrounding municipalities. The reservoir covers approximately 736 ha (1,820 acres) at an elevation of 307 m (1,006 ft) msl at conservation pool, with the top of its flood control pool at elevation 320 m (1049 ft) msl. An initial objective of the project was to restore spawning and nursery fishery habitat for gamefish, including largemouth bass, crappie, and bluegill. However, as the project grew in scope, additional objectives were added that include (a) evaluating the suitability of selected native emergent, floating-leaved, and submersed aquatic species for establishment in the lake, (b) developing effective methods for establishing desirable aquatic plant species, and (c) establishing founder colonies of aquatic plants in several areas of the lake. In addition to providing immediate nursery habitat for juvenile fish, these founder colonies were expected to provide propagules for natural spread to other areas of the lake.

A task force for developing and implementing the Arcadia Lake restoration effort developed a strategic overview of the project in May 2021 that added additional objectives and a year later the project appears ready to be initiated (Cadamy and Hopper 2021). One of the central objectives of the project is to reestablish native emergent vegetation. The criteria used to identify potential sites for planting at Arcadia Lake were (a) protection from wind and wave action, and (b) substrate texture – sites with soft substrate characteristics ranging from sandy to muddy were selected (Dick et al. 2004). If establishing an emergent plant community (see

Restoration Site E, in Section IV) meets with favor, several criteria developed for plant selection at Arcadia Lake may be appropriate for Horseshoe Reservoir as well, including selecting emergent/wetland plant species that are: (i) native, (ii) not deemed noxious, and (iii) have high tolerances to changing water level fluctuations. Ultimately, 12 emergent species were selected for Arcadia, including species of the genera *Eleocharis* and *Scirpus* that may be species to consider for revegetation actions at Restoration Site E or for other locations in Horseshoe Reservoir.

One challenge noted by Arcadia Lake managers was the challenge posed by herbivory by a multitude of wildlife species; carp and semiaquatic turtles were of particular concern in this regard (Dick et al. 1995). Both large-scale and small-scale enclosures were constructed at Arcadia in response to herbivory threats. Small scale enclosures protected individual plants, while large-scale enclosures included installation of lengthy fence lines to protect entire coves and targeted shorelines (Dick et al., 2004). However, results at Arcadia indicate that many aquatic and emergent plant species established and thrived without such protection (Dick et al. 1995). Both large-scale and small-scale enclosures were constructed at Arcadia in response to herbivory threats. Small scale enclosures protected individual plants, while large-scale enclosures included installation of lengthy fence lines to protect entire coves and targeted shorelines (Dick et al., 2004). However, results at Arcadia indicate that many aquatic and emergent plant species established and thrived without such protection (Dick et al. 1995).

In addition to the above, one of central lessons to come out of the Arcadia Lake project was the importance of conducting pilot revegetation efforts prior to scaling up to an appreciable level. Such an approach should be considered as part of establishing native bottomland plant communities within the Horseshoe Reservoir study area.

Contact Information: Arcadia Lake Task Force (see Cadamy et al. 2021).

BEAR RIVER, CALIFORNIA

Floodplains that are regularly inundated for extended periods are important for their high production of organic matter and invertebrates as well as for the provision of seasonal spawning and/or rearing habitat for native fishes. A recent CALFED-sponsored study identified criteria for quantifying floodplain flow requirements. Coined ``floodplain activation flow'' or FAF a study was initiated on this topic that hypothesized that there is very little remaining FAF floodplain in the Central Valley, because of a combination of flow regulation, channel incision and levee construction. In addition, the study noted that, as a result of floodplain development, there may be few areas where FAF floodplains can readily be restored without either dramatic changes in reservoir management or levee setbacks. As such, those areas where FAF floodplains can be restored should be high priorities for the restoration community since they offer floodplain function benefits across a broad range of flood magnitudes and support essential ecosystem functions and anadromous fish habitat.

A site of particular importance in this regard is at the confluence of the Feather and Bear Rivers between Sacramento and Yuba City, where a major levee setback was implemented in summer and fall of 2006 as part of a multi-objective flood control and habitat restoration project (Stofleth

et al. 2007). The setback will restore 66 acres of floodplain to river flows, with much of the restored floodplain area meeting the FAF criteria. One of the facets of this restoration effort that may be relevant to restoration at Horseshoe Reservoir concerns the identification of future investigations that may be priority. In the case of Bear River, physical process data were collected to develop two models: a geomorphic assessment that included the development of a two-dimensional sediment transport model to assess the potential consequences of the setback on aggradation and deposition processes on the Feather or Bear Rivers, and a two-dimensional hydraulic assessment to optimize habitat restoration on the newly activated floodplain.

Such is not underscored to promote model development as part of next steps associated with bringing back Horseshoe Reservoir, but offered as an example of a project where involved personnel could talk about the cost and value of such modeling. Was such modeling worth the effort and expense? Are there cheaper ways to get at the same information or to address the same questions? Bear River personnel may be in a good position to address these and similar questions if such is of interest to SRP as part of completing next phases of the Horseshoe restoration effort.

Contact Information: Three Rivers Levee Improvement Authority - https://www.trlia.org/citizen_request/index.php (Leslie Wells is Executive Administrator at Three Rivers and can provide further direction depending on focus of follow-up questions)

ELEPHANT BUTTE RESERVOIR, NEW MEXICO
Elephant Butte Reservoir is located in the southern region of New Mexico about 5 miles (8.0 km) north of Truth or Consequences (Fig. 2). The construction of Elephant Butte dam was authorized by the United States Congress on February 25, 1905 to provide flood control and irrigation down-river. The name stems from an isolated hill (a volcanic plug that is now surrounded by water) that resembles an elephant[5]. Construction began in 1911 and was completed five years later, in 1916. The dam is 301 feet (82m) high and 1,674 feet (510m) long. At the time of completion, it was the second largest dam in the world with its reservoir and the waters it provided contributing to the largest irrigation enterprise in the United States. At conservation pool (surface water elevation of 4,406.3 ft (1,343m)), the reservoir behind the dam stores 2,210,298 acre-feet (272,636 ha-m) of water, which is the largest body of water in New Mexico that, even at its lowest levels, provides an array of recreational opportunities that include boating and fishing. The dam also has a 24,300-kilowatt hydroelectric power plant at its base, which began operating in 1940.

At conservation pool level, Elephant Butte Reservoir holds about 2.3 million acre-ft (0.28 ha-m) of water. Pool volume has varied dramatically since the reservoir began to store water. The reservoir was at or above conservation pool elevation for much of 1924 and 1942. And, during significant parts of the period between 1983 and 1989, the reservoir was above 80% capacity. However, the trend has been generally downward since. In the summer of 2013, Elephant Butte Reservoir dwindled to near empty with the total water in storage in July 2013 estimated at 65,057 acre-feet (8,025.5 ha-m), which is about 3 percent of the reservoir's capacity. The surface water elevation and volume has increased since 2013 but nowhere near pool capacity with the

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[5] Coincidentally there is evidence that actual prehistoric elephants roamed the area with the finding near Elephant Butte in 2014 of the skull and tusks of a 3.2 million-year-old stegomastodon.

current water elevation at about 4,310 ft (1,314m) with an average pool elevation of 4,318 ft (1,316m) since 2013.
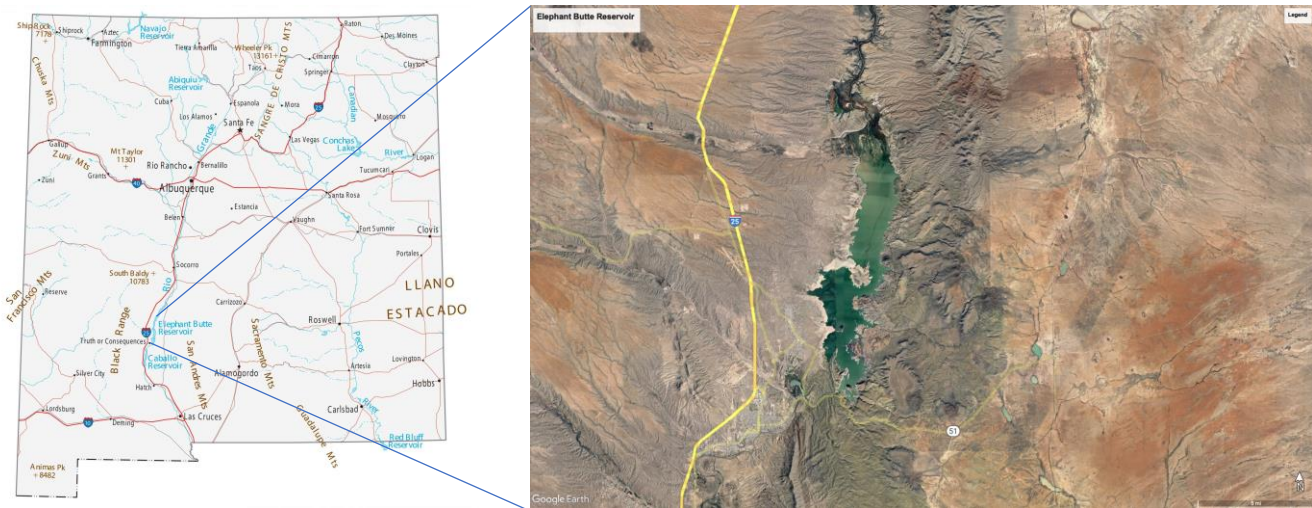
Figure 2. Location of Elephant Butte Reservoir in south central New Mexico (left) with recent aerial photograph of the reservoir and the immediate area around it (right).

The decline in pool elevation and volume since the late 1980s has resulted in a consummate dramatic decline in how far the pool extends upstream of the dam, which is about 34 miles (55 km) when the pool is at conservation status to its current position of about 10 miles (16.1 km) upstream of the dam. This has allowed a roughly 25-miles (40 km) reach of the river that was dominated for over a half century by an artificially imposed impoundment hydrology to once again experience natural flow processes that are not characterized by significant periods of inundation. In the wake of this decline in pool elevation, a large swath of native obligate riparian species (mostly *Salix gooddingii* and *S. exigua*) have established, particularly on the western side of the Rio Grande channel (Fig. 3). The extensive presence of healthy coyote willow (*S. exigua*), in particular, is a key understory component at Elephant Butte Reservoir that contributes to the suitable habitat for Southwestern Willow Flycatcher. Although present at Horseshoe Reservoir, it is uncertain if this willow species could be as abundant or robust at Horseshoe Reservoir as it is at Elephant Butte Reservoir.

The reestablished native obligate riparian plant community provides habitat for a variety of native species, including the Federally endangered Southwestern Willow Flycatcher (*Empidonax traillii extimus*; hereafter referred to as SWFL), which thrives in bottomland ecosystems characterized by wet floodplains with a shrubby component (Moore 2020). The establishment of such high-quality obligate riparian habitat without active management intention and along a significant reach of a mainstem river that was previously dominated by the imposed hydrology of river impoundment prior to what Reclamation personnel consider to be a quasi-permanent retreat of the reservoir pool underscores two central take home lessons to restoration actions being contemplated at Horseshoe Reservoir.

First, the extensive high-quality native bottomland habitat in areas dominated for numerous years by the imposed hydrologic environment of Elephant Butte Reservoir underscores just how dramatic and rapid the reestablishment of native habitat can be when natural processes return. Although the two settings – Horseshoe Reservoir along the Verde and Elephant Butte Reservoir along the Rio Grande – differ with regard to their biophysical characteristics, the rapid reestablishment of high-quality native habitat in the Elephant Butte delta is nonetheless heartening to the prospects of restoring native bottomland plant communities at Horseshoe Reservoir.

Figure 3. Photograph of the extensive obligate riparian plant community that has established on over 40 km (25 miles) of the MRG reach upstream of the Elephant Butte Reservoir.

The second take home from the Elephant Butte Reservoir experience is that the rapid reestablishment of native habitat just upstream of the reservoir occurred without active management intervention by the US Bureau of Reclamation or anyone else. The native obligate riparian plant community reestablished naturally as the reservoir retreated. Looking ahead in this report to the restoration sites proposed at Horseshoe Reservoir, the above lessons are possibly more apropos for Restoration Site A, which, being the upstream most restoration site, is where natural streamflow processes are likely to strongly reestablish if Horseshoe Reservoir management becomes dominated by run-of-river management. The experience at Elephant Butte underscores how the return of natural flow processes at reach scale has great potential to foster natural regeneration of native bottomland habitat.

Contact information: Christopher M. Grosso (US Bureau of Reclamation) and Lawrence E. Moore (US Bureau of Reclamation)

ELWHA RIVER, WASHINGTON

The Elwha River flows for 72 km from steep terrain in the Olympic Mountains to the Strait of Juan de Fuca on Washington's Olympic Peninsula. The decision to remove the Elwha and Glines Canyon dams on the Elwha River, Washington was preceded by the collection of substantial amounts of biological and physical data. Studies were conducted to identify existing water quality within the reservoirs and river, fish populations and habitat availability, fish passage mortality through the dams and reservoirs, effects of the hydro-power projects on wildlife habitat, and economics. Monitoring of many of these attributes has continued during and following dam removal, which was carried out in phases over a two-year period from September 2011 to September 2013. The Elwha River system may be one of most studied in the world, at least with regard to quantifying the impacts of dam removal (see for example, East et al. 2015; Magirl et al., 2015; Prach et al. 2018). Although there are vast differences between dam removal and changes in dam management (as in the case of Horseshoe Dam), the treasure trove of documentation on how the Elwha River system is reacting to dam removal may provide insights on a variety questions of pertinence to how biophysical and chemical characteristics of Horseshoe Reservoir may be affected by run-of-river management. For example, Prach et al. (2018) found that spontaneous restoration of vegetation on fine sediments in drained lake bottoms can rapidly produce a desirable vegetation composition and structure, and that invasive species were much less abundant following the removal of Glines Canyon Dam than expected. Again, the Elwha River system and situation is distinctly different from Horseshoe Reservoir, but the breadth of studies that have taken place on the Elwha River system is inviting and may be worth exploring in greater detail.

Contact information: See literature cited, above, in connection to Elwha River restoration. All authors are likely candidates for follow-up.

KLAMATH RIVER, OREGON

The aging dams near the Oregon-California border were built before current environmental regulations and essentially cut the 253-mile-long river in half for migrating salmon, whose numbers have plummeted. The project on California's second-largest river would be at the vanguard of a push to demolish dams in the U.S. as the structures age and become less economically viable and as concerns grow about their environmental impact, particularly on fish (Flaccus 2022). Regulators have emphasized that moving ahead with the proposal to remove the dams along the Klamath would "maximize benefits" to salmon fisheries important to local tribes and restore the landscape to a "more natural state." Removal of the four sites, including the J.C. Boyle, Copco No. 1., Copco No. 2 and Iron Gate dams, would restore the river's free flow from southern Oregon to Northern California and then the Pacific Ocean over a 20-month period.

Although the Klamath River and the Verde River differ significantly with regard to geography, climate, hydrology, amongst other considerations, the process of dam removal along the Klamath has sparked or relied on a variety of studies on dam removal that may be of interest to SRP in the context of how changes in management at Horseshoe Reservoir may impact reservoir biophysical and chemical conditions (see for example Stanley and Doyle 2003; Swanson et al. 1988; Oliver et al. 2014). In this sense, the Klamath River case study is much like that of the Elwha River, above, with regard to the studies that are taking place to understand and anticipate

biophysical change and develop a thoughtful adapted management program centered on such anticipated changes.

Contact information: See literature cited, above, in connection to how the removal of dams along the Klamath River may impact conditions. All authors are likely candidates for follow-up.

ISABELLA RESERVOIR and KERN RIVER, CALIFORNIA

Located 35 miles northeast of Bakersfield, Isabella Reservoir was created at the confluence of the North and South forks of the Kern River in Kern County, California (Fig. 4). The CE Isabella Project was authorized by the Flood Control Act of 1944 to protect the city of Bakersfield and construction was completed in 1954 (Warner and Hendrix 1984). The reservoir was built primarily to support agricultural irrigation with excess water diverted into the California Aqueduct. The reservoir resulted in the loss of approximately 1,300 ha (3,212 acres) of riparian forest with remnant forests surviving to date on a mix of lands managed for conservation, including 125 ha (308 acres) of dense riparian forest at the Kern River South Fork inlet that is managed as the South Fork (Kern River) State Wildlife Area with additional riparian forests managed upstream as part of the Kern River Preserve, which is managed by the National Audubon Society (Fig. 4). The South Fork of the Kern River supports one of the largest contiguous riparian forests in California and is habitat for Western Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*), Southwest Willow Flycatcher (*Empidonax traillii extimus*) and Least Bell's Vireo (*Vireo bellii pusillus*) (Warner and Hendrix 1984, Anderson, et al. 1978). The South Fork Wildlife Area (SFWA) is within the high-water mark of Isabella Reservoir and designated by the Sacramento office of the Army Corps of Engineers as a conservation area. The SFWA was initially considered as a unique example of preservation and enhancement of riparian biodiversity. After construction, the reservoir reached full capacity twice, in 1960 and 1980. As of September 2022 the reservoir is at 8% capacity as a result of prolonged drought and drawdowns for construction at the dams.

A planned change in reservoir operations that would increase inundation frequency prompted a 1980 baseline study evaluating the effects of the 1980 inundation to the riparian habitats and bird populations (Fleshmann and Kaufmann 1981). They noted that plants are more susceptible to stress from inundation during the growing season. They concluded that Fremont cottonwood (*Populus fremontii*) was least tolerant and Goodding's willow (*Salix gooddingii*) the most tolerant to prolonged inundation. Teskey and Hinckley (1977) considered Fremont cottonwood able to withstand one-three months of inundation and Goodding's willow able to withstand being flooded for most of a growing season. One of the more significant vegetation changes at Isabella Reservoir was the change in open field vegetation from mustards (*Rorrippa* and *Descurainia* spp.) and grasses (*Graminae*) to cocklebur (*Xanthium*). In marsh areas, cattail (*Typhus*) did not regenerate and was replaced by curly dock (*Rumex*) and monkey flower (*Mimulusgttatus*) (Fleshmann and Kaufmann 1981). Post inundation vegetation communities were simplified with loss of cottonwoods and cattail and a commensurate decline in bird species diversity and density.

The U.S. Army Corps of Engineers is addressing dam safety with an in-progress Isabella Dam Safety Modification Project that includes raising the dams to original design heights. The final Finding of no Significant Impact (FONSI) was issued September 25, 2022. To date, 144 acres

have been designated as mitigation for the Isabella DSM Project. Of this, sixty-four acres are within the boundaries of the 1,316-acre South Fork Wildlife Area, owned and managed by the US Forest Service, Sequoia National Forest. The South Fork Wildlife Area is known as one of the most extensive riparian woodlands remaining in California. The proposed conservation area lies above the maximum pool of the lake in an area currently without any tree canopy as a result of a fire in 2011. The additional 80 acres are at Sprague Ranch, owned and managed by the Audubon Society. The proposed 80-acre Sprague Ranch site is located on relatively flat land and was previously disturbed by agriculture. Dominant plant species include native and non-native annual grasses and perennial shrubs including Bromus species, Rumex species, broadleaf (*Erodium Botrys*) and redstem (*Erodium acutarium*) filaree, salt grass (*Distichlis spicata*), wild cucumber (*Marah macrocarpa*), and a few medium stature Fremont cottonwood (*Populus fremontii*). The Sprague Ranch holds historic water rights to the Cottonwood Ditch on the South Fork Kem River, which may be managed to improve habitat on the proposed conservation area. Habitat restoration at both sites is expected to benefit Western Yellow-billed Cuckoo. As the riparian habitat matures within the conservation areas, it is expected that the restoration activities will improve habitat conditions for the southwestern willow flycatcher. (USFWS Biological Opinion Update 2016)
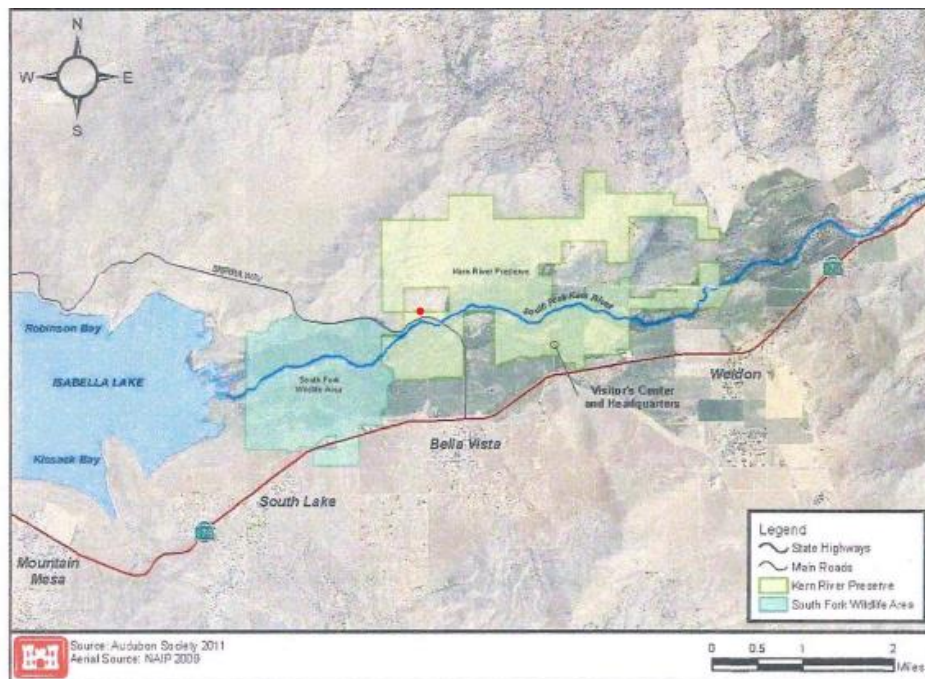
Figure 4. Location of South Fork Wildlife Area and Sprague Ranch conservation areas of the Kern River Preserve.

The impacts of reservoir operation change on vegetation conditions is of interest, particularly with regard to how invasive and undesirable species such as mustards and cocklebur may also become a challenge to establishing native bottomland habitat at Horseshoe Reservoir. A future visit to see how the vegetation restoration is being implemented on the 144 acres at South Fork Wildlife Area and Kern River Preserve may be valuable.

Contact information: isabella@usace.army.mil ; https://kern.audubon.org/; Kern River Ranger District 760-376-3781

PINE FLAT LAKE

The construction of Pine Flat Dam on the Kings River in the Central Valley of Fresno County, California altered the natural hydrologic and temperature regime of the river. This in turn affected riparian and adjacent vegetation, restricted native coldwater fish movements and wildlife resources at Pine Flat Lake and along the Kings River downstream of the dam. To address these issues, the Army Corps of Engineers (ACE) and the Kings River Conservation District (KRCD) proposed the construction of a multilevel intake structure on the upstream face of the dam to manage the temperature of downstream water releases, fostering downstream water temperatures suitable to sustain native cold-water fish throughout the year. As part of this effort, KRCD and ACE proposed to reestablish historic floodplain riparian and wildlife habitat at Byrd Slough along the Kings River immediately south of the Friant-Kern Canal siphon, with the overall aim to bring back bottomland habitat restoration along about 13 miles of the lower Kings River, improve the cold water fishery in the reservoir, and restore about 143 acres of riparian and shaded riverine aquatic habitat at Byrd Slough (KRCD and ACE 2001).

Although future management of Horseshoe Reservoir will have nothing to do with cold water fisheries, the restoration of historic floodplain riparian habitat fits well with what is being contemplated restoration-wise at Horseshoe Reservoir. It may be valuable to follow up with ACE and/or KRCD personnel for an update on this project and lessons learned, particularly with regard to the restoration of bottomland habitat.

Contact information: Jeff Halstead is the Chief of Kings River Conservation District, Environmental Division; and Judy Soutiere is the Corps project manager for the study. The contact for further information is given as: Charlotte Gallock, KRCD (cgallock@krcd.org)

ROOSEVELT RESERVOIR, ARIZONA
Rockhouse Demonstration Project, Roosevelt Lake, Arizona

In 2003, the Salt River Project (SRP) initiated the Rockhouse Riparian Demonstration Project to satisfy components of the Roosevelt Habitat Conservation Plan (HCP), which calls for the development of an approximately 20-acre (8 ha) site of woody riparian vegetation within a 5-year period to provide habitat for southwestern willow flycatcher (*Empidonax traillii extimus*), yellow-billed cuckoo (*Coccyzus americanus*), and bald eagles (*Haliaeetus leucocephalus*).

The Rockhouse site is located approximately 100 miles (160 km) northeast of central Phoenix just upstream of Roosevelt Lake at an elevation of 1,998 feet (609 m) (Fig. 5). The site is segmented into eight fields that were planted over the four-year period from 2004 through 2007. In preparation for the project, planting areas were contoured and leveled, and an existing historic irrigation channel that transports water from the Salt River at the Salt River Diversion Dam was rehabilitated. In general, soils at the site are sandy loam that overlay a thick profile of cobbly-sandy alluvium. Groundwater depths range from 20 to 30 feet (6m to 9 m), which necessitated

the use of irrigation to establish and maintain such shallow-rooted species as cottonwoods and willows.

To meet habitat objectives for the aforementioned bird species, the Rockhouse site was planted with Fremont cottonwood (*Populus fremontii*) and Goodding's willow (*Salix gooddingii*) for the overstory component, and seep willow (*Baccharis salicifolia*) and coyote willow (*Salix exigua*) were planted in later revegetation phases to augment vertical complexity. the understory component and Prosopis spp. regenerated naturally. Vegetation actions were carried out in four distinct phases during the course of the four-year implementation period. By the summer of 2009, a total of 1,018 cottonwood trees and 173 Goodding's willow trees were successfully established in the majority of the phases of the revegetation effort, and an additional several hundred were established as part of later phases in basins to the north and south of initial plantings. Most of the individual cottonwood plants were prepared and planted as 1-gallon containers, while the remainder and all of the Goodding's willows (43) were installed as pole plantings. All of the plants were harvested from the City of Phoenix Rio Salado project, which is located near central Phoenix.[6]
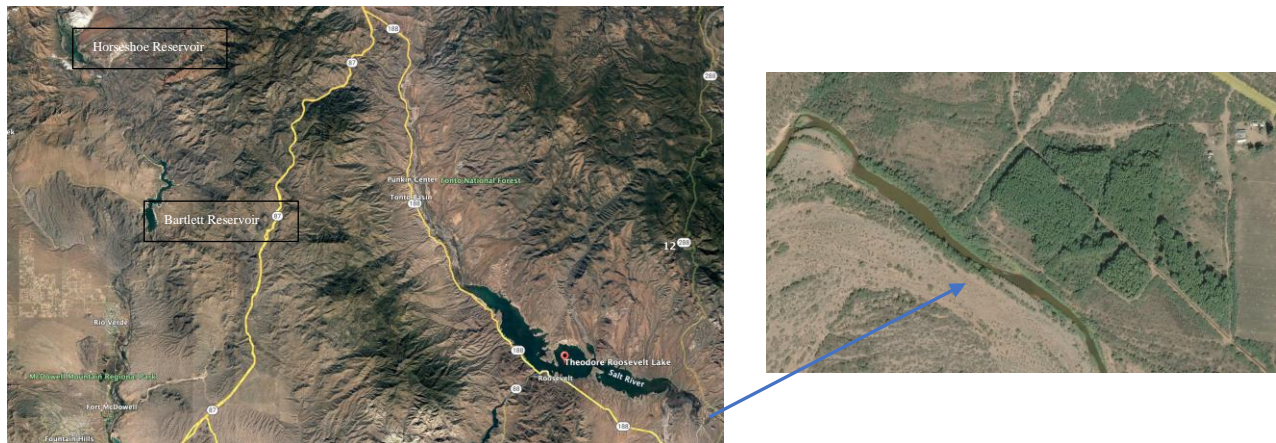
Figure 5. Google Earth images showing location of Rockhouse Demonstration Project site (at right in 2019) in context of Horseshoe Reservoir, Bartlett Reservoir and Roosevelt Lake.

Project results were evaluated in September 2008 by biologists from SRP, the US Fish and Wildlife Service (FWS), US Bureau of Reclamation (Reclamation), and Tonto National Forest (TNF). The evaluation found that vegetation efforts were successful in establishing woody riparian vegetation on approximately 20 acres (8 ha) (Figs 6 and 7). Site monitoring in the summer of 2009 confirmed the presence of three yellow-billed cuckoos utilizing the habitat created by the project and by the summer of 2010 five flycatcher territories were documented.

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[6] The Rockhouse Riparian Demonstration Project final report (currently in draft form) provides details on planting methods. These details are not summarized here given that, if revegetation efforts are conducted in the future at Horseshoe, they will likely be implemented without irrigation. That noted, pole plantings without irrigation may take place at Horseshoe. A key lesson to come out of the Rockhouse Demonstration project with regard to pole plantings is the importance of placing the poles into saturated soils as well as soaking them prior to planting.

Figure 6. Photograph of a mature stand of dense cottonwoods and willows at the Rockhouse Demonstration site attest to the effectiveness of revegetation actions to establish habitat for key bird species (photograph taken December 2022).

Figure 7. Photograph of scattered non-native saltcedar has established at the Rockhouse site, though the high density overstory of cottonwoods and willows has shaded out and prevented significant expansion of this invasive species at this site. Establishing a high density overstory to thwart expansion of non-native species is a potential applicable lesson for future revegetation efforts at Horseshoe Reservoir.

<u>Main Lessons Learned from Vegetation Efforts at Rockhouse and Roosevelt Lake (in general)</u>
1. Importance of knowing soils, in particular matching site soil physical and chemical characteristics to species selection was considered key to high plant survival and strong growth at the Rockhouse site. This lesson has strong bearing at Horseshoe, particularly with regard to characterizing physical and chemical characteristics of the soils at several of the proposed restoration sites located along the reservoir's shoreline that were frequently inundated under past management. Reduced inundation under run-of-river management may open up some of these sites to natural and/or artificial establishment of native plant habitat. If artificial revegetation efforts are considered, the proposed plant

    pallet for each site will need to be based, at least in part, on a clear understanding of the site's soil chemical and physical characteristics.

2. Monitoring and adaptive management are important particularly with regard to staying on course to meet restoration objectives

3. Maintenance is critical, particularly during initial stages just after restoration actions have been completed when establishing desired plant species are most vulnerable to competition from undesirable plants, desiccation, amongst other factors. Of course, conducting maintenance actions requires funding that allows maintenance actions to continue for years following the completion of restoration implementation activities.

4. Understanding the challenges as well as opportunities for establishing native vegetation along reservoir shorelines will be critical at Horseshoe Reservoir. The variation of water levels at Roosevelt Reservoir (along with many reservoirs throughout the world, including Horseshoe) creates harsh conditions for vegetation establishment in areas along the shoreline or perimeter of the reservoir that are both inundated for prolonged periods of time then left high and dry (sometimes for years) when the reservoir pool recedes. This harsh reservoir zone is often characterized by limited vegetation establishment and is often referred to as a reservoir bathtub ring. On one hand, many native upland and non-obligate riparian plants are not able to establish in this zone due to their intolerance to prolonged inundation. On the other hand, many obligate riparian species are not able to establish due to prolonged periods when the saturated soil zone drops below their shallow root systems during hot, dry periods.

Harsh shoreline zones relatively free of vegetation was a characteristic in many other parts of Roosevelt Reservoir. For example, at the Orange Peel site along the shoreline where Tonto Creek meets the Reservoir edge; prolonged periods of inundation followed by periods of reservoir pool retreat have created conditions where even many invasive non-native species cannot survive (Fig. 8). At Horseshoe Reservoir, shoreline sites that were frequently inundated under past management could become suitable to the establishment of desirable native bottomland habitat under run-of-river management that reduces the frequency and duration of inundation. Planting desirable plants at such sites will need to be done carefully, taking into consideration a variety of factors, including the rate of drawdown to allow plant root systems to follow retreating saturated soil levels.

Figure 8. Photograph of a part of the southern shoreline along Roosevelt Reservoir underscores the challenges of that frequent periods of prolonged inundation followed by retreat of the reservoir pool pose to vegetation establishment.

SECTION THREE
CENTRAL CHALLENGES TO ESTABLISHING NATIVE PLANT COMMUNITIES WITHIN THE HORSESHOE RESERVOIR STUDY AREA

INTRODUCTION

In this section, the main challenges to establishing native plant communities in compromised bottomland environments are reviewed as a basis for identifying criteria useful to selecting promising restoration sites in Horseshoe Reservoir. Identifying and presenting these 'challenging factors' as site selection criteria also allows each of the proposed restoration sites to be thoughtfully compared to one another. For example, as will be discussed in greater detail below, scouring of newly planted vegetation is one of the main factors that many bottomland revegetation efforts do not realize their intended objectives. Therefore, vulnerability to flood scour (or protection from flood scour) is one of the criteria used to both select restoration sites in Horseshoe Reservoir restoration as well as a means of comparing the potential of restoration site to others (e.g., proposed restoration site D may offer greater protection to planted vegetation from flood scour than restoration site B for reasons x, y and z).

It is important to note that the identification of challenging factors that have a strong bearing on determining the success of bottomland restoration efforts is founded on a long, well-documented track record of bottomland restoration/revegetation efforts that have provided numerous lessons learned for the benefit of future projects (Briggs 1996; Stromberg et al. 2004; Shafroth et al. 2008; Shafroth and Briggs 2008; Briggs et al. 2020; many others). In the context of introducing 'challenging factors' as a basis for site selection criteria at Horseshoe Reservoir, it is important to note that challenging factors come from both the non-ecologic and ecologic side of the bottomland restoration coin. Non-ecologic factors include such important considerations as funding availability, permitting, site access, community support, etc., while ecologic factors include such considerations as vulnerability to flood scour, water availability, competition from non-native plants. The focus here will be on reviewing challenging factors from the ecological side of the coin.

As we identify the key challenging factors and use them as criteria for identifying potential restoration sites at Horseshoe Reservoir, we need to keep in mind that restoration is taking place in a 77-year old reservoir that embodies all of the impacts of river impoundment. These impacts include altered longitudinal gradients caused by an unnatural water regime that has fostered upstream–downstream shifts in physical, chemical, and biological processes (Oliver et al. 2014; Ward and Stanford, 1983). Excessive suspended sediments and sedimentation, interruption in natural conveyance of sediment, water and nutrients as well as excessive nutrient loadings, erosion and lack of woody debris in the littoral zone, limited access to backwaters and wetlands, the demise of native riparian and aquatic vegetation, increase in non-native species, and in some cases excessive growth of aquatic vegetation are some of the key specific impacts of impoundment (Humborg et al., 1997; Kelly, 2001; Friedl and Wüest, 2002; Friedl et al., 2004; Miranda 2008; Wang et al., 2014; Huang et al., 2019; dos Santos et al., 2020; Wang 2020).

Restoring native plant communities in reservoirs of arid regions is particularly challenging, as the primary function is capture and storage of spring season and storm runoff followed by drawdown for human uses. The result is dramatic annual fluctuation in water levels within the reservoir and in the immediate upstream river segments. One manifestation of this is that reservoirs in the arid southwest often have an un-vegetated bathtub ring that delineates the area from maximum high water to minimum pool drawdown. This is certainly the case in Horseshoe Reservoir where significant portions of its shoreline are either dominated only by annual plants or are relatively free of vegetation.

In Horseshoe Reservoir, conservation pool elevation (near 2,026 ft) occurred six times during the time period of 1-1-02 to 1-1-22. In some cases, surface water elevations remained at conservation pool status for over a month. For example, in 2005, the surface water elevations behind the dam remained at 2,025 ft or greater for a period of 78 days, then dropped precipitously to a surface water elevation just above the reservoir flow where it remained until the next large flow event occurred. From the standpoint of an obligate riparian or non-obligate riparian plant, such significant fluctuations in water surface elevations with extended durations can be intolerable. Although such obligate riparian species as *P. fremontii* and *Salix* spp. can survive extended inundation periods, repeated inundation of long duration can be stressful, particularly if inundation periods are followed by dramatic drawdown that allows soil saturation levels to drop below plant root zones. Such a situation can be a devastating one-two punch to obligate many riparian plants and is possibly the reason why many obligate riparian plants that managed to establish in the past in Horseshoe Reservoir were not able survive for a long period of time.

As we consider restoring native bottomland plant communities in Horseshoe Reservoir it is important to keep two contradictory thoughts in mind at the same time. First, even with Horseshoe Dam operated as run-of-river with gates wide open the majority of time, the dam will still be present, impounding river flow and impacting physical, chemical and biological processes. This needs to be constantly taken into account as restoration sites in Horseshoe Reservoir are identified and restoration tactics developed.

Second, operating the dam with gates wide open the majority of time will presumably reduce the frequency and duration that the reservoir contains significant volumes of water. Certainly, Verde River flow will continue to pool behind the dam even with gates wide open. Dam outflow cannot compete with a high magnitude Verde River flood event of significant duration. If river discharge remains high for a long period of time (e.g., during an extensive wet period), surface water elevations behind the dam could remain at or near conservation pool status throughout the duration of that wet period, even with gates wide open. Regardless, the trend under a run-of-river management regime will be one of diminished frequency that large volumes of water pool and remain behind Horseshoe Dam for extended periods of time. In a nutshell, impoundment will still impact natural processes, but less so. Biophysical and chemical processes will be more suitable to both natural and artificial establishment of native bottomland plants.

With that as background, let's turn out attention to the ecological factors that have a strong bearing on determining success of riparian revegetation projects in arid environments with the aim of using these 'challenging factors' as criteria for identifying and assessing the proposed

Horseshoe Reservoir restoration sites summarized in Section IV. Again, we are not considering non-ecological factors here, which can have as much a bearing on determining success of bottomland revegetation efforts as ecological factors. Documented results of numerous bottomland revegetation efforts along streams reveal that the degree of success (i.e., how well bottomland revegetation efforts realized their objectives) was determined by five main ecological factors: water availability, flow scour, prolonged inundation, competition from non-native plants, and elevated soil salinity. These five factors are reviewed, below, with eye towards using them as criteria for identifying and evaluating the proposed Horseshoe Restoration sites.

WATER AVAILABILITY AND FLOOD SCOUR

Of the five factors that have a strong bearing on determining the success of bottomland revegetation efforts, the two standout factors are water availability and flood scour. That is, low water availability or drought (i.e., planted vegetation desiccates) and flood scour were identified as the two key factors behind high mortality rates of planted vegetation (McBride and Strahan 1984; Briggs and Osterkamp 2020; Bunting et al. 2020a).

Reichenbacher (1984) described riparian communities in terms of a continuum of stability. The most unstable communities are on surfaces that experience frequent flooding; typically, these are active floodplain surfaces that are closest to and only slightly higher in elevation than the stream channel. In contrast, on the stable end of the continuum, are surfaces that are higher in elevation and further removed from the stream channel (such as floodplain terraces), where flood disturbances are relatively infrequent. Particularly in the context of establishing obligate riparian plants and wetland plants in the arid climate of southern Arizona, the challenge is that the greater the elevation difference between the channel thalweg and planting surface (i.e., surfaces that are flooded less frequently and more toward the stable portion of the continuum), the less water is typically available to allow plants to establish and survive in the long-term. This is particularly true during the months of May and June in the southwestern U.S. when precipitation is typically minimal, temperatures are high (with consummate high plant water needs with high evapotranspiration rates), and streamflow is a trickle, in the case of average conditions for the Verde River during these months, or non-existent, in the case of ephemeral tributaries like Lime Creek, Mullen's Creek, and Deadman's Wash.

In the context of assessing potential restoration sites for establishing desirable plants at Horseshoe Reservoir, a key question with regard to water availability is, are average conditions of water availability at the site during the driest, hottest time of the year adequate to allow establishment and long-term growth of desired plants? Several factors determine the amount of water that will be available for plant use. These include streamflow, flow regime, the water-absorptive capabilities of the plant species, age of the plant, climate, soil type, soil salinity, and depth to ground water. Based on the long-term streamflow data collected at Tangle Creek, average flow during May and June is 3.8 m^3/sec (134 ft^3/sec) and 2.5 m^3/sec (87 ft^3/sec), respectively. Evapotranspiration and transmission losses between the Tangle Creek confluence and the reservoir will reduce average Verde River flow into Horseshoe Reservoir further. Average Verde River flow into and through Horseshoe Reservoir will be a trickle with flow on average confined to the thalweg and immediate channel (i.e., not covering floodplain surfaces).

Although some early studies found that *P. fremontii* and *S. gooddingii* can satisfy some of their water needs from the soil vadose zone (McQueen and Miller 1972), accessing the saturation zone appears key to survival (Stormberg 1993). With that in mind, it is important to note that many obligate riparian plants such as *Salix* spp., *P. fremontii*, *Fraxinus* spp., etc. are characterized by shallow root systems that typically cannot access water if the elevation of the saturated zone falls more than 3 m below soil surface (Zimmerman 1969; Jackson et al. 1987[7]; Busch et al. 1992; Stromberg et al. 1991).   Although root systems of *P. fremontii* seedlings can grow rapidly (6-13 mm/day), they will have a difficult time surviving if the rate of shallow groundwater decline is greater than 3 cm per day (Fenner et al. 1984; Pope 1984; Mahoney and Rood 1991). To survive the first few years of growth, seedlngs need to be planted on surfaces where the soil saturated zone is within 1-2 m of the establishment surface (McBride and Strahan 1984; Mahoney and Rood 1992). For newly planted species, the saturated zone must be even closer to the surface of the soil for young plants with developing root systems. Therefore, how far and quickly the elevation of the surface saturated soil zone drops in elevation during May and June following the winter-spring wet period is critical information for assessing potential restoration sites for these species.

Within the Horseshoe Reservoir Study area, sites that likely offer water availability conditions suitable for the establishment and long-term survival of obligate riparian and wetland plants are sites with the elevation of potential plant establishment surfaces are not significantly greater than the Verde River thalweg (the lowest part of the channel). Given how flat the central portion of Horseshoe Reservoir is, one of the important unknowns is the extent to which the elevation of the soil saturated zone drops with increased distance from the thalweg. In addition, sites toward the southern end of the reservoir in close proximity to Horseshoe Dam may also offer conditions of relative high water availability. It is in this portion of the reservoir where water will frequently pool even if the dam is managed in the future with gates wide open. Such pooling of water may foment shallow saturated soil conditions not only in the immediate area of the pool, itself, but also a zone immediately surrounding the pool.

In the context of identifying sites in Horseshoe Reservoir that potentially offer conditions of suitable water availability for restoration, the focus up to this point has been on establishing obligate riparian and wetland plants, both of which require near-surface saturated soil conditions to survive. The native plant restoration footprint within Horseshoe Dam can be greatly expanded if non-obligate riparian plants are also considered. Deeper rooted species like mesquite, for example, are not as limited as most obligate riparian species and can access water from much greater depths. A future where the operation of Horseshoe Reservoir is operated run-of-river should reduce the footprint, duration, and frequency that the reservoir is inundated, potentially opening up significant parts of the system to the establishment of such plants that are vulnerable to inundation but have wider amplitude for surviving dry and hot conditions.

With regard to flood scour, newly planted species are much more vulnerable than mature plants of the same species. Depending on the substrate, at least a year of root growth is needed for a seedling to become sufficiently anchored to allow it to survive a modest flood event. If a

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[7] In their study of cottonwoods along the San Pedro River, Jackson et al. (1987) found mature, healthy cottonwoods on surfaces where shallow groundwater elevations routinely dropped 4 m below the soil surface during the hot, dry months prior to the onset of southwestern U.S. monsoon season.

revegetation site experiences a high magnitude flood the week after plants are put in the ground, it is likely that many will be lost downstream. If the same flood event occurs a year after planting, losses will likely be less dramatic.

Going back to the streamside stability continuum noted by Reichenbacher (1984), the great challenge for all revegetation efforts that aim to establish obligate riparian plants in an active bottomland environment is finding the sweet spot the offers some protection to newly planted vegetation from scour while providing suitable water availability. On one extreme, desired species could be planted on terrace surfaces that are outside the current active flow environment. Such a strategy would nearly guarantee protection from flood scour but would be problematic from a water availability standpoint (particularly for shallow-rooted obligate riparian plants that are unable to access saturated soils that are greater than three meters below the soil surface). On the other extreme, desired species could be planted on surfaces adjacent to and only slightly higher in elevation than the stream channel. Such would likely offer sufficient water availability but little protection from flood scour. The establishment sweet spot is somewhere between those extremes.

That noted, within the active bottomland environment there are surfaces with inherently greater vulnerability to flood scour as well as those of similar elevation above the channel that are much less vulnerable. Avoiding the former while exploiting the latter is key to success for revegetation. For example, surfaces on the outside of a meander bend where water velocity energies are greatest often show signs of sediment evacuation, cut banks and vegetation scour should be avoided. In contrast, planting on the inside of a meander bend where flow energies are reduced with calmer waters depositing heavier sediments is much more likely to be successful. In addition to the inside of meander bends, other types of channel surfaces and channel characteristics that can protect planted vegetation from flood scour include wide and topographically diverse surfaces as well as surfaces just downstream of large boulders or other impediments that offer lee-side flood protection. As mentioned above, sediment is deposited at slower water velocities, as heavier materials such as sand and cobble can settle out. Fallen trees, logs, displaced boulders, and other obstructions provide the roughness to reduce the speed of streamflow and promote interspersed areas of aggradation.

Given that no site within an active bottomland environment is immune to scour, planting a diversity of sites that offer increased protection from flood scour will improve the likelihood that at least some will survive. For example, planting a range of elevations that extend from primary floodplain surfaces to higher secondary floodplain surfaces is often a prudent strategy. Secondary channels and oxbows with relatively high water availability can offer refuges from scour that increase opportunities for survival and long-term persistence of obligate riparian vegetation (and in some cases, emergent wetland species as well). Finding these and other parts of the active bottomland environment that offer high water availability while providing refugia during high flow is an inherent part of the design of successful bottomland revegetation efforts (Bunting et al., 2020a; Stella et al. 2011).

In addition to parts of the Horseshoe Reservoir study area that have some of the above flood scour protection characteristics, the topography of the study area offers other characteristics. First, the main consequence of constructing a dam across a river is the interruption of flow and

impoundment of water behind the dam. As such, flow scour as a potential threat to newly planted vegetation within the Horseshoe Reservoir system may be reduced even if Horseshoe Dam is operated as run-of-river. In addition, and possibly more important, the reservoir area is relatively unconstrained by surrounding topography. It is wide with a low slope, providing a setting that fosters significant dissipation of flow energies when flows arrive at the reservoir and spread out. As such, of the two big two challenging factors to bottomland revegetation projects – low water availability and flood scour – flood scour may be less of a challenge to establishing native bottomland plants in and around the periphery of Horseshoe Reservoir compared to desiccation.

SOIL SALINITY

Most obligate riparian plants have low tolerances to soil salinity. Typically, elevated soil-salinity levels are not a problem along healthy streams where frequent flooding prevents the buildup of salts. However, soil salinity can become elevated where human activities (such as agriculture) and altered hydrologic processes have diminished water quality and reduced or eliminated flooding and the associated leaching or flushing of salts (Vandersande et al. 2001; Anderson 2017). Elevated soil-salinity levels can also occur where ground water is consistently near the surface and where stream waters are high in total dissolved salts (Anderson and Ohmart 1982). This has become a problem in many parts of the world. In Victoria, Australia, for example, abnormally high levels of soil salinity have contributed to the decline of native riparian communities along the Murray-Darling River (Hart et al. 1990; Jolly et al. 1993).

Another example closer to home are the agricultural practices in the Colorado River Basin that have greatly affected water quality, with the river picking up an estimated 7.7 million tons of salt per year (USBR 2013). In a review of revegetation experiences at 29 sites along the lower Colorado River over a two-decade period, Anderson (2015) concluded that assessing soil type and measuring electroconductivity (EC) levels—a proxy for soil salinity—in the first and fourth quarters of the soil profile (between the surface and just above the zone of saturation) were key variables in determining the potential success of establishing cottonwoods and willows. He concluded that a two-fold increase in salinity (i.e., EC measurements increasing from 1-2 mmho/cc) resulted in a 20 percent drop in potential cottonwood and willow growth. It should be cautioned that in situ measurements of EC can vary by method and may not be directly comparable between sites (e.g., portable meters and field sensors are analyzed differently than an augered core sample sent to laboratory for saturated paste extract).

The lack of data and information on soil salinity in the Horseshoe Reservoir study area makes it difficult at this point to use soil salinity thresholds as criteria for identifying potential planting sites or, conversely, to eliminate them from consideration. That noted, parts of Horseshoe Reservoir that in the past were frequently inundated for extended periods of time are more likely to have enhanced soil salinity levels in comparison to sites that were less frequently inundated. In this regard, northern or upstream portions of the Horseshoe Reservoir study area may be less of a concern with regard to the buildup of soil salinity compared to sites closer to the dam. In addition, the potential benefits of managing Horseshoe as run-of-river (reduced frequency and duration of significant pooled waters behind the dam) will likely reduce salt buildup in parts of the reservoir and may even flush out excess salts in areas where salt buildup has occurred.

In general, high soil salinity levels as a challenging factor is less of a concern to the viability of vegetation planted as part of future Horseshoe revegetation efforts, at least as compared to losing planted vegetation via desiccation and flood scour. Elevated soil salinity may be more of a challenging factor when the following factors occur together as part of a revegetation plan: (i) Obligate riparian plants with low tolerances to salinity (such as *P. fremontii* and *Salix* spp.) are being considered as part of the revegetation pallet; (ii) The site that is being considered was frequently inundated in the past; and (iii) Obligate riparian plants have not established in the site in the recent past (such establishment would indicate soil salinity levels acceptable for establishment and growth of obligate riparian plants). If the above three factors do occur jointly, soil salinity measurements may be warrened. Soil sampling methods to map soil-salinity levels at potential riparian revegetation sites, are reviewed by Briggs (1996). Reviews of tolerances of selected riparian plants to soil salinity and planting techniques that may help establish plant species with low salinity tolerances in areas characterized by elevated soil salinity are also available (Briggs 1996; Anderson 2015; Bunting et al. 2020a).

COMPETITION FROM UNDESIRABLE PLANTS

The riparian revegetation world is full of examples of projects overrun with non-native, undesirable plants following the completion of planting activities (i.e., where competition from undesirable vegetation was excessive and led to high mortality of vegetation planted as part of the revegetation effort). It is often difficult to predict the level of competition from non-native plants that may occur at different sites following planting. Certainly, sites already choked with an invasive species should be considered problematic in this regard. Portions of the Horseshoe Reservoir shoreline that are frequently inundated but left high and dry for significant periods of time are dominated by such pioneer invasives as *Amaranthus palmeri*, *Xanthium spinosum* (spiny cocklebur), *Cynodon dactylon* (bermuda grass), amongst many others.

Putting all the other challenging factors aside for the moment, a site dominated by such undesirable invasives should be lower on the priority revegetation list compared to sites that do not have such challenges. However, a site with high densities of invasive, undesirable species should not be unilaterally ruled out for several reasons. First, the above species can be controlled, though control methods, the footprint of control efforts, and timeframe need to be carefully developed as part of the overall revegetation plan. Second, management efforts should not endeavor to rid the entire revegetation site of such species (such would be expensive and time consuming, and possibly even impossible). Instead, management or control objectives should aim to eliminate the sites undesirable vegetation from the immediate footprint of the vegetation being planted. And, third, the revegetation effort, itself, may be part of the solution to reduce the extent and distribution of such undesirable vegetation via shading and competition.

In addition to using the extent and distribution of undesirable, invasive plants as a means to compare potential revegetation sites at Horseshoe Reservoir, SRP may want to develop a targeted list of undesired, invasive species that it will manage if those species are found within the Horseshoe Reservoir study area. A long-term management objective should also be finalized for each specie on the target list for each site. The long-term objective could vary with both specie and site. For example, the long-term objective for controlling saltcedar at Restoration Site A may be to tolerate its presence at certain levels, while the management objective for Tree of

Heaven may be to eradicate it completely. Regardless, finalizing such long-term objectives with a plan to accomplish them should be a priority that would promote the maintenance of the extent and distribution of proven problematic invasive plants in Horseshoe Reservoir at manageable levels (before an invasive species got out of control. Management actions to control invasive species does not have to be expensive, if management actions are conducted consistently and are based on thoughtful, collaborative and realistic long-term management objectives (Briggs et al. 2021).

Four non-native plants that are particularly invasive and troublesome throughout much of the Verde River are: *Ailanthus altissima* (Tree of Heaven), *Arundo donax* (giant cane), *Elaeagnus angustifolia* (Russian Olive), and *Tamarix ramosissima* (saltcedar). An overview of these species and options for managing them is provided in the Appendix.

PROLONGED INUNDATION

As defined here, inundation is when the majority of a plant's surface is underwater. Prolonged inundation can interfere with transpiration processes to the point of compromising plant vigor (Amlin and Rood 2001). Tolerances of native riparian plants to prolonged inundation vary and may be a factor to consider as part of identifying promising sites in the Horseshoe Reservoir study area for establishing native bottomland vegetation. In a natural setting, prolonged inundation (more than a month) of plants in a bottomland environment rarely occurs. But, behind a dam, even a dam like Horseshoe that may be operated as run-of-river, prolonged inundation may be a challenging factor; one to consider as part of selecting sites for establishing desirable bottomland plant species. For example, a scenario of prolonged above-average precipitation in the Verde River watershed (a winter and spring of above-average precipitation with Verde River flow being driven by runoff from rain and snowmelt) may lead to prolonged inundation of parts of the reservoir even with Horseshoe Dam gates wide open. Although the trend with run-of-river management in place at Horseshoe Reservoir will be a reduced frequency and duration of large pools establishing behind Horseshoe Dam, such will still occur and some sites will be prone to prolonged inundation more than others.

In the same vein but looking at inundation as a complicating factor from another perspective, there are sites that were frequently inundated in the past but will likely not be in the future under run-of-river management. Particularly for shoreline sites that fall in this category, the reduced frequency and duration that they are inundated in the future will lead to drier conditions. The drier conditions may remove establishing obligate riparian plants as a realistic possibility but could make such sites conducive for establishing non-obligate riparian plants that are vulnerable to inundation (at least generally more so than obligate riparian plants) but can survive in drier conditions. The proposed revegetation sites reviewed in Section Four will be assessed and compared to one another both with regard to looking at sites where prolonged and frequent inundation may still be a challenge, and therefore a complicating factor, as well as looking at sites where run-of-river management may present opportunities as the frequency and duration they are inundated is reduced.

SECTION FOUR
PROPOSED SITES FOR ESTABLISHING NATIVE BOTTOMLAND HABITAT IN HORSESHOE RESERVOIR

OBJECTIVE

Changing the management of Horseshoe Dam to run-of-river will influence the reservoir's biophysical and chemical characteristics, likely significantly so. The extent of change remains an open question, but operating Horseshoe Dam with gates wide open the majority of the time will move the natural process needle toward 'natural' with the assumed manifestation of offering opportunities for establishing native bottomland flora and fauna that were not possible under the former management regime. Restoration opportunities at Horseshoe Reservoir may be expanded if the changes in water management are accompanied by such on-the-ground restoration actions as revegetation, limited earthmoving, managing non-native invasive plants, etc. The main objective of this section is to summarize sites within the Horseshoe Reservoir Study Area that show promise for native obligate riparian, non-obligate riparian and wetland emergent plant communities[8] either via natural regenerative processes or via artificial revegetation actions.

Three points to emphasize before summarizing the Horseshoe Reservoir sites that appear to offer greatest restoration potential. First, we use the term 'restoration' in this context broadly, defining the term in the context of this report as any effort whose aim is to improve biophysical conditions of an ecosystem. As such, we are not narrowing the overall aim to a specific past time (e.g., pre-European settlement). The intent is broad, covers a large swath of potential biophysical endpoints that carry the intention of improving habitat and overall conditions for native wildlife and/or people.

Second, the term 'restoration site' is used in this context to refer to portions of Horseshoe Reservoir that appear to have: (i) similar biophysical conditions (similar hydrology, hydraulics, soil chemistry, riparian vegetation conditions), and (ii) restoration potential, either via natural processes alone or via the implementation of on-the-ground restoration actions (e.g., revegetation, management of non-native plants, limited earth moving, etc.). Particularly if on-the-ground restoration actions are undertaken, the footprint of these actions will likely occur on only a portion of what is currently delineated as a potential restoration site.

Third, results of additional field investigations, compilation and analysis of additional data collected via monitoring, results of pilot revegetation projects, and other efforts to fill in pertinent information gaps, as well as other factors, will determine the extent that SRP pursues restoration actions at any of the proposed sites. In other words, it is expected that, as additional data and information are gathered and analyzed, some of the proposed restoration sites summarized below may be eliminated from contention and other sites not currently being considered may be added.

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[8] When referred to collectively, this group of native plant communities – obligate riparian, non-obligate riparian and wetland/emergent – are often referred to as native bottomland plant communities.

BACKGROUND

In general, perennial lakes and reservoirs have four distinct and interacting biotic communities: (i) the riparian zone that is not submerged for significant periods of time; (ii) the wetland-littoral zone and its sediments; (iii) the open water pelagic zone, and (iv) the benthic or deep water (profundal) zone and sediments.

The riparian zone is often dominated by woody river floodplain species that, in the southwestern U.S., often includes such obligate riparian native species as cottonwood (*P. fremontii*), willows (*Salix gooddingii*, *S. exigua*, and other *Salix* species), Ash (*F. velutina*), amongst many others, and, depending on the setting, such non-native trees as Russian Olive (*Elaeagnus angustifolia*) and saltcedar (*Tamarisk* spp.). Both lakes and reservoirs are strongly linked to the land via nutrient and silt loading, as well as through detritus imports from the littoral and riparian zones. Riparian vegetation is important for aquatic ecosystems, since it provides habitat for many species, controls fluvial erosion, and functions as a biological filter of pollutants between terrestrial and aquatic zones. Riparian vegetation also serves as wildlife habitat and ecological corridors, retains sediment, and protects aquatic ecosystems from agrochemical contamination (Lowrance, 1998; Micheli and Kirchner, 2002; Cortez-Silva et al. 2020).

In addition to identifying sites where native obligate riparian habitat can be established within the Horseshoe Reservoir study area, this report will also include sites where non-obligate riparian plant communities could be established, which includes such species as mesquite (*Prosopis* spp.), acacia (*Acacia* spp.), netleaf hackberry (*Celtis reticulata*), saltbush (*Atriplex* spp.) amongst others, that are typically found on secondary floodplain and terrace surfaces that are higher in elevation and less frequently affected by streamflow. As important as obligate riparian woodlands are to providing high quality habitat, it important to note that non-obligate riparian plant communities also provide high quality habitat for numerous species. For example, southwestern willow flycatcher and Yellow-billed cuckoo both nest and/or use such habitat when its available along with numerous other bird species outside the mitigation requirements of the Environmental Species Act, including Phainopepla (*Phainopepia nitans*), Black Phoebe (*Sayornis nigricans*), Verdin (*Auriparus flaviceps*), Vermillion flycatcher (*Pyrocephalus rubinus*), Great Horned Owl (*Bubo virginianus*), Gray Hawk (*Buteo plagiatus*), Belted Kingfisher (*Megaceryle alcyon*), amongst many other bird and other wildlife species.

The inclusion of non-obligate riparian plants as part of this study's recommendations is also critical from the standpoint they are better adapted to and, therefore, capable of establishing and thriving in the long-term, in parts of the bottomland environment that are drier and have higher soil salinity than the immediate floodplain environment where obligate riparian species typically establish. Such is certainly important given the prognosis of a future climate that will be drier and hotter than in the past.

Moving from the riparian zone to surfaces of lower elevation, the wetland-littoral zone of any body of water is inundated the majority of time and is often dominated by emergent, floating and submerged vascular plants. The littoral zone can have high species diversity and is commonly the site where fish reproduction and development occur. It is also critical for waterfowl habitat. Although the establishment of obligate riparian and non-obligate riparian plant communities are a main emphasis of this report, emergent wetland plants are considered and is a central objective

for at least one of the proposed restoration sites summarized below. With regard to the open water and deep-water zones mentioned above as part of a 'typical' reservoir or lake system, these zones are not a focus of this report. Particularly if Horseshoe Reservoir is managed in the future as a pass-through or run-of-river system, the open water and deep-water zones are likely to be limited and possibly absent for most of the time.

PROPOSED HORSESHOE RESERVOIR RESTORATION SITES

Six sites (A-F) have been identified in Horseshoe Reservoir as having potential for establishing native bottomland plant communities in a future dominated by run-of-river management (Fig. 9).
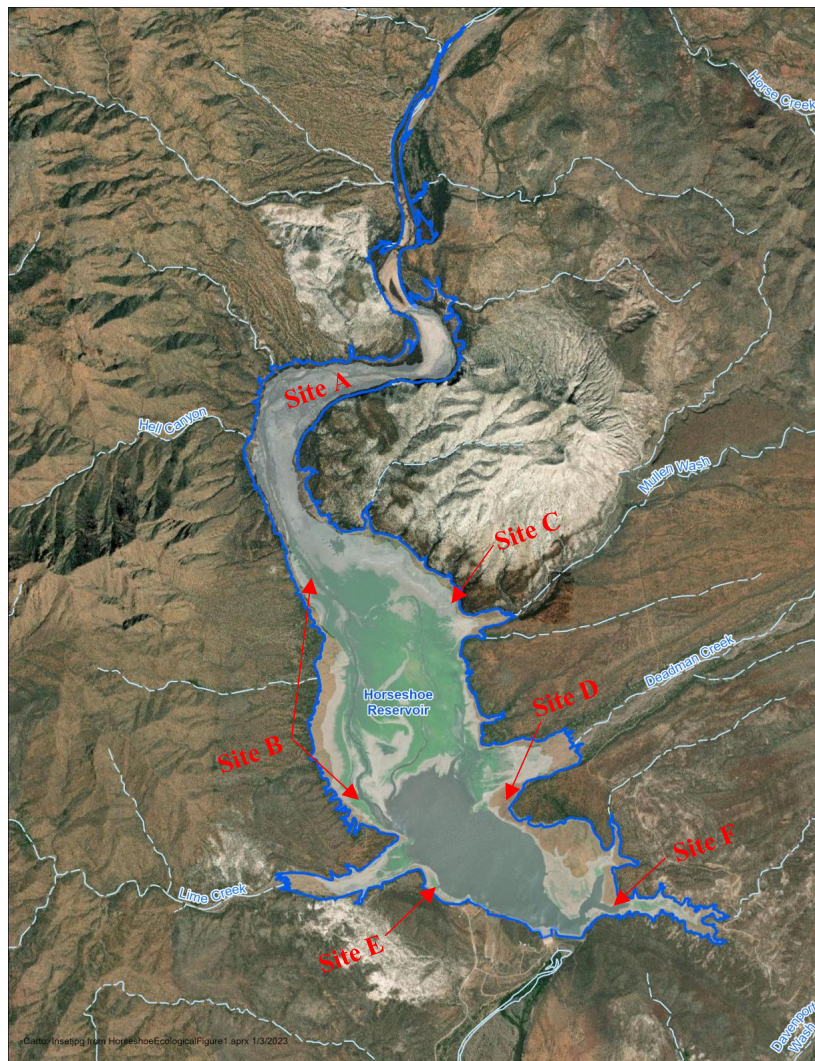

Figure 9. Overview image of Horseshoe Reservoir showing locations of proposed restoration sites A-F (image provided by SRP Cartographic & GIS Services).

As noted above, the spatial footprint for a particular restoration site encompasses parts of the Horseshoe Reservoir environment with similar biophysical conditions (similar hydrology, hydraulics, soil chemistry, riparian vegetation conditions) and restoration potential. Restoration sites are presented, below, in an upstream to downstream direction. Site summaries focus on the attributes summarized in Section III that are considered key to evaluating the potential for the establishment of native bottomland plants in a given location. As current knowledge gaps are addressed, the location and footprint of the restoration sites are likely to change.

RESTORATION SITE A
Overview
Restoration Site A is a series of floodplain surfaces along the Verde River that extend from the most upstream portion of the Horseshoe Reservoir study area to where the Verde River bottomland environment widens significantly south of Chalk Mountain (Fig. 9). In the context of discussing Restoration Site A and the upstream portion of Horseshoe Reservoir, it is important to note that although the hydro morphology of rivers and ecological effects downstream of dams are well studied and documented (Petts, 1980; Williams and Wolman, 1984; Ligon et al., 1995; Grant et al., 2003; Graf, 2006; Yang et al., 2014), relatively little is known about the effects in upstream river segments (Petts and Gurnell, 2005; Wohl, 2015). The factors affecting the upstream river channel include fluctuating water levels, changes in sediment transport and deposition, higher groundwater levels (Simon, 1979; Kaczmarek et al., 2016), and increased frequency of inundation in the floodplain terraces adjacent to the reservoir (Baena-Escudero, etal. 2021., Evans et al., 2007; Liro, 2014). These factors influence the development, species composition, and retention of riparian vegetation (Lite et al. 2005; Sun et al., 2012), and presumably have affected biophysical conditions of the Verde River bottomland environment in Restoration Site A.

Advantages and Drawbacks
With the above noted, it appears that the Verde River bottomland environment of Restoration Site A experiences natural flow and channel dynamics, at least in comparison to parts of the reservoir further downstream that are impacted to a much greater degree by the hydraulic buffering effects of Horseshoe Dam. Insights gleaned from natural resource scientists, SRP staff, and study of aerial photography going back to 1985 reveal periods when the Verde River channel and riparian vegetation community of Restoration Site A changed dramatically as well as periods of relative stability. For example, a comparison of aerial photographs of the central portion of Restoration Site A shows the Verde River channel having a tight meander bend in 2006 that shifted to the northwest by 2015 with apparent dramatic changes in the extent and distribution in the riparian vegetation community along this reach between 2006 and 2012. Such changes in channel morphology are indicative of a natural, dynamic river system.

High magnitude flow events in January of both 2008 and 2010 probably drove some of the channel changes that can be observed between the aerial images of 2006 and 2012 (Fig. 10). In contrast, changes in channel form and sinuosity appear minor along the same reach from 2015 to date. Taken together, the swing between periods of dramatic channel morphologic change and periods of relative stability reflect a dynamic environment responding to natural boom-bust

hydrologic cycles (Fig. 10). Periods of dynamic morphologic and riparian vegetation change take place with the occurrence of high magnitude flow events of sufficient duration to perform dramatic channel work as alluvium is scoured and evacuated from one part of the channel and deposited along downstream reaches. Such a dynamic environment fosters a channel physical template ideal for the establishment of a natural, patchy riparian plant community dominated by native vegetation and is the central reason why Site A was selected as a restoration site.
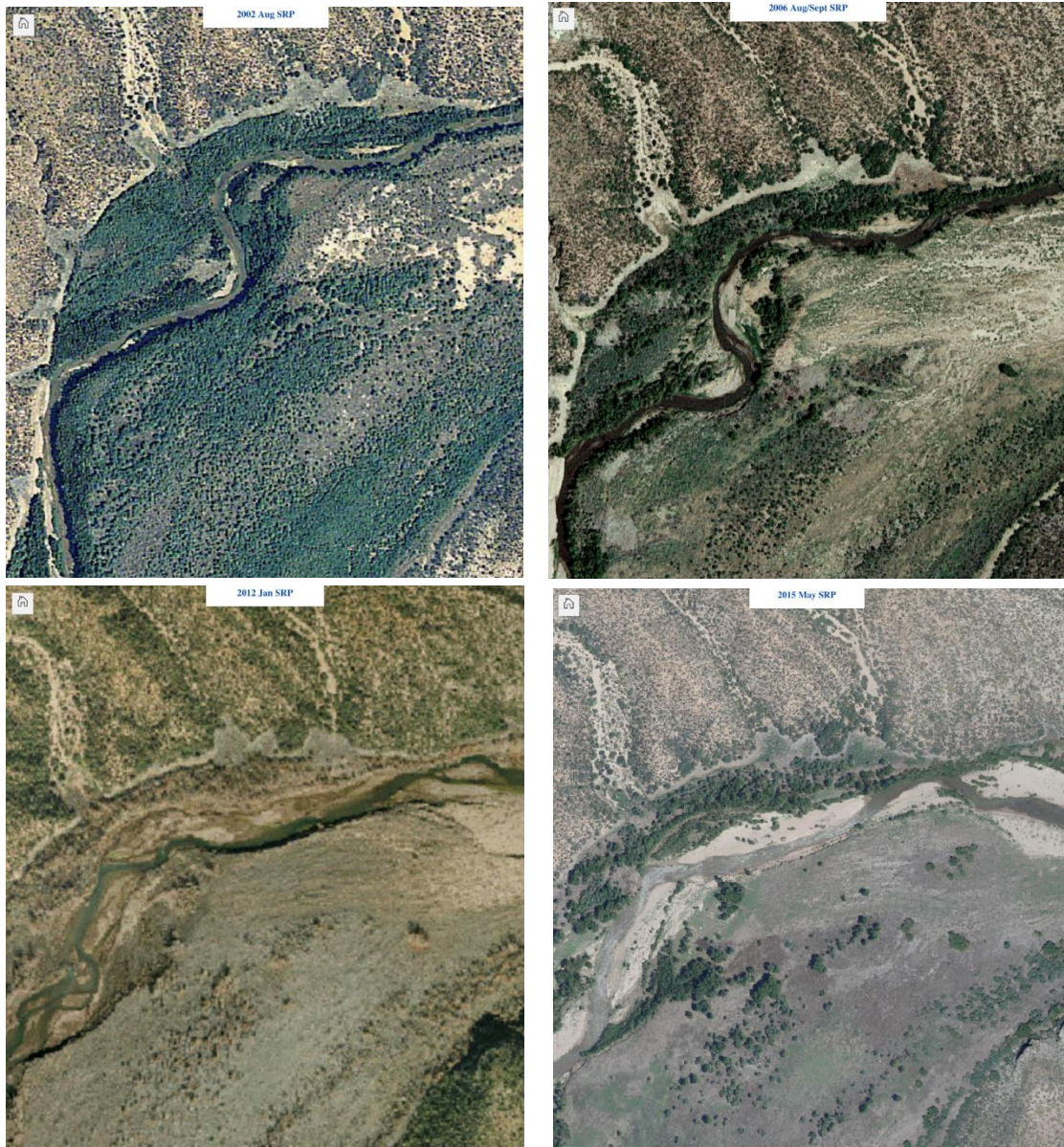

Figure 10. Google Earth aerial images of the central portion of Restoration Site A in August 2002, August 2006, January 2012, and May 2015. Morphologic changes in the Verde River channel between these different time periods are evident (particularly when images of August 2006 and January 2012 are compared) and likely as a result of high flows that occurred during 2008 and 2010.

Although the Verde River channel at Restoration Site A reflects a more natural flow environment than downstream study reaches, it has undoubtedly also been affected by river impoundment. Horseshoe Reservoir was held at conservation pool elevation (2,026 ft) six times from 2002 to 2022, with durations of inundation at that elevation lasting in some instances over a month. For example, in 2010, the surface elevation of Horseshoe Reservoir was at conservation pool elevation from April 17th to May 25th. In 2020, the reservoir was at conservation pool from March 20th to May 3rd (Fig. 11).

During these periods, Verde River flow energies are buffered as they enter the reservoir and make contact with pooled waters, likely reducing the frequency and extent that sediment along this part of the channel or reservoir was re-worked in a manner that promotes natural and suitable conditions for the regeneration of obligate riparian plants. With regard to the proposed restoration sites (Restoration Site A and others as well), an important hydrologic modelling question to address in the near future is, to what extent will run-of-river management affect the frequency and duration that they are artificially inundated by impounded waters? With a subsequent question being, how will such changes in inundation frequency and duration affect flood scour, water availability, soil salinity, plant competition and other factors important to understanding what the response of the native bottomland plant community might be?
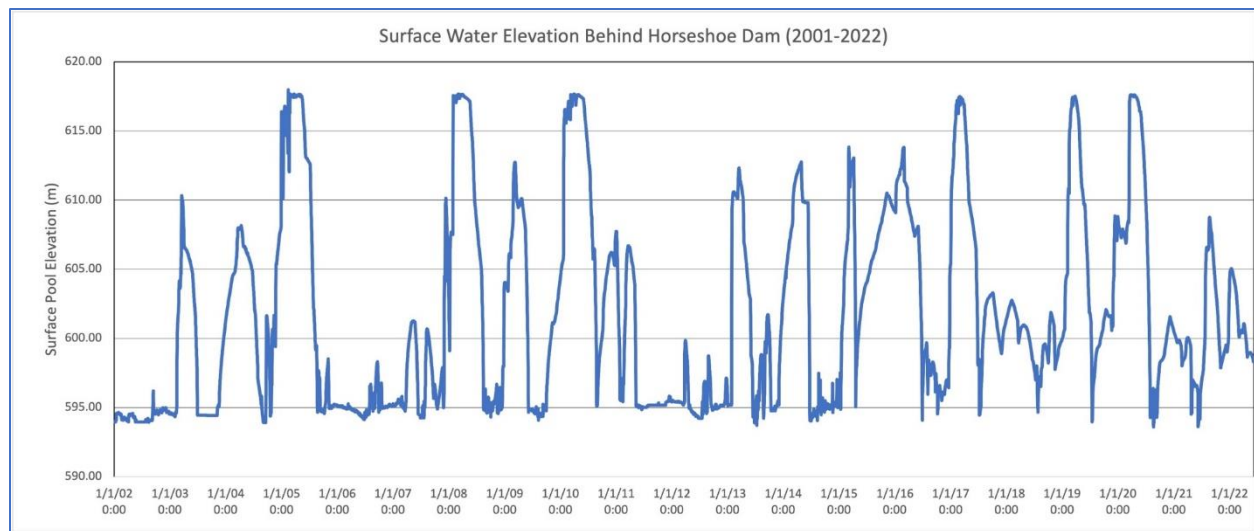
Figure 11. Surface water elevation of Horseshoe Reservoir pool for years 2001 to 2022. During this period, the reservoir pool reached and was held at conservation pool status six times for several weeks to over a month (surface water elevation data provided by SRP).

As a first step to addressing this question, topographic data from remote LiDar and multispectral imaging platforms were collected and organized for targeted channel transects (or cross-reservoir transects, depending on transect location) cut through the digital elevation point cloud data to quantify the extent of topographic change along the transects over the last two decades. One such transect was cut across the Verde River channel in the central portion of Restoration Site A for three different years, providing an accurate assessment of not only current topographic conditions at that transect location but also how channel topography has changed in the recent

past (Fig. 12). At least at this conceptual stage in developing restoration options for Horseshoe Reservoir it is appropriate to expound on the information that transect number one provides as a general representation of channel morphologic change along the Verde River channel throughout Site A. With that generality in mind, it appears that much of the bottomland environment of Restoration Site A is under water when the surface elevation of the reservoir pool is 614 m (2,013 ft) or greater. Analyzing daily surface elevation data of the Horseshoe Reservoir pool from 2001 to 2021 indicates that a surface water elevation of 614 m occurred 9.1% of the time during that 20-year time period.
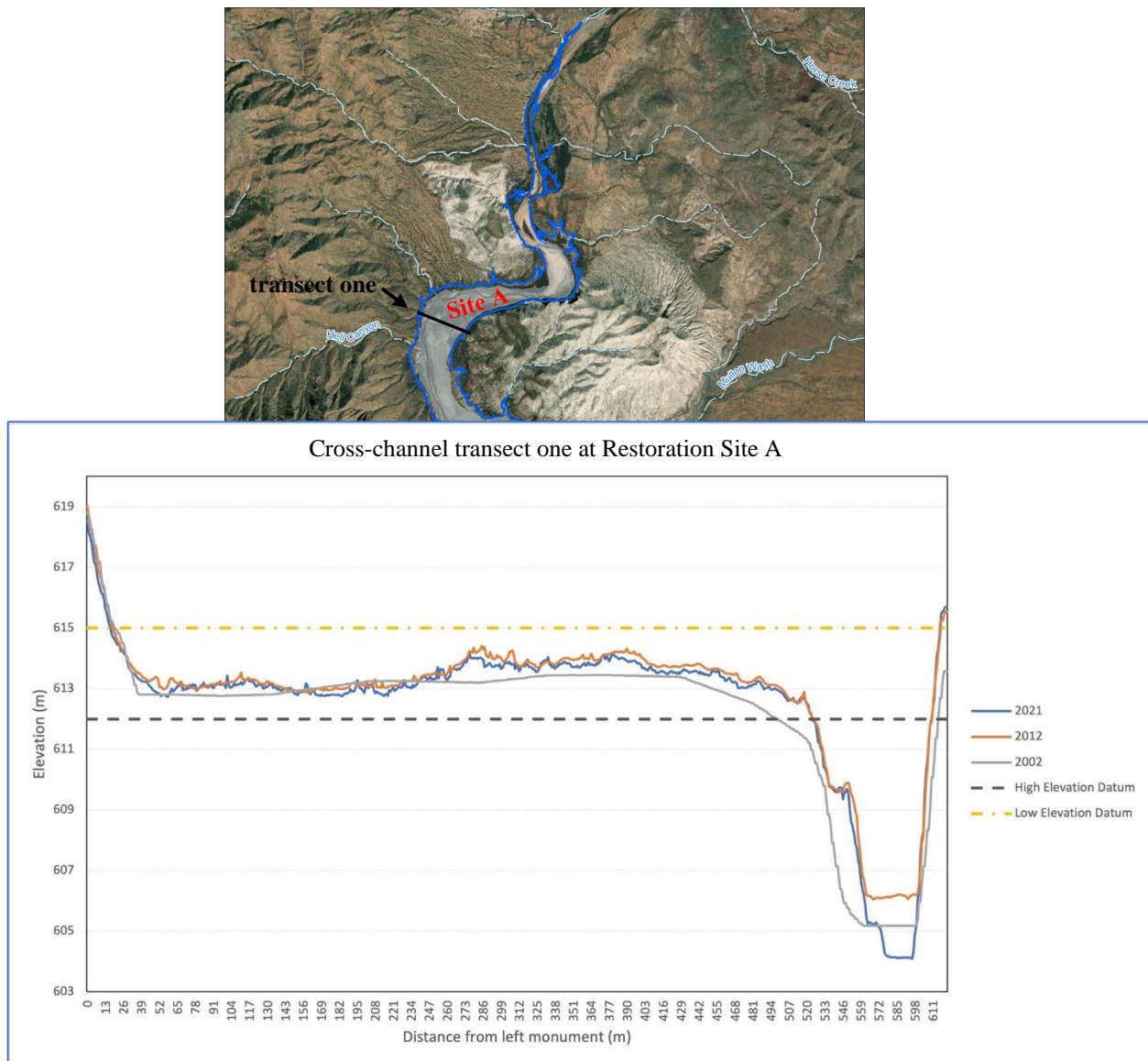
Figure 12. Cross-channel transect across the Verde River channel cut through topographic point cloud data four in the central portion of Restoration Site A for years 2002, 2012, and 2021. Topography data for the 2021 and 2012 are derived from aerial LiDar coverage, while topography from 2002 are derived from multispectral imagery (as such is less accurate than data collected via LiDar technology). Position of transect one is shown in the image above.

Being located at the upstream most portion of the reservoir, it is likely that a future dominated by run-of-river management will likely reduce the frequency and duration that Restoration Site A is inundated by impounded waters behind Horseshoe Dam, with potentially consummate repercussions on natural flow dynamics that will translate to enhanced natural regeneration of the obligate riparian plant community along this reach. The question is, how much? Modelling how surface water elevations of the reservoir pool are impacted when Horseshoe Dam is managed with gates wide open will provide insights to answering this question. In addition, initiating a long-term program at Site A to monitor channel morphology and riparian vegetation will provide data needed to quantify site biophysical response to management changes.

An additional observation regarding Restoration Site A is that channel surface diversity along this reach may offer opportunities to encourage the establishment (naturally and/or via artificial plantings) of both non-obligate and obligate riparian plant communities. Such appears particularly true along the portion of the Verde River channel from where it turns abruptly west and follows the northern flank of the Chalk Mountains to where the channel turns abruptly south and passes to the west of Chalk Mountain (Fig. 12). Along this portion of the reach, surfaces adjacent to but slightly higher in elevation than floodplain surfaces may be conducive to establishing native mesquite bosque habitat, while lower elevated surfaces may be suitable for obligate riparian species.

Restoration Site A could move up the priority ladder even further if future investigations verify this assumption. Diversity in channel bottomland surfaces often correlates to diversity in bottomland plant communities. The mix of distinct channel surfaces is highlighted in cross-sectional elevation data obtained from remote LiDar and multispectral imagery platforms. In Figure 13, secondary floodplain and terrace surfaces to the left of the low flow channel are likely much more protected from flood scour (at least compared to the low-flow channel), yet with inherent lower water availability. Though such surfaces are still part of the active bottomland environment, their physical characteristics may be more conducive to the establishment and long-term viability of non-obligate riparian plants than obligate.

In comparison, and not surprisingly, the low flow channel is much more dynamic with its banks and primary floodplain surfaces more conducive to obligate riparian plants. High and low elevation datums were used to quantify changes in channel cross-section area between 2012 and 2021 (2002 cross-channel data were not used given the large error bars associated with developing topographic data from multispectral images (versus LiDar data that constitute evaluation of morphologic changes for 2012 and 2021)). Calculating cross-sectional areas under the low elevation datum for more than one time period provides a means to understand gross morphologic change of the low-flow channel. An increase in cross-channel area between different time periods indicates overall sediment evacuation, while a decrease indicates aggradation. Subtracting cross-sectional areas for different time periods under the low elevation datums from those under the high elevation datums quantifies changes in cross-section area for such higher elevated surfaces as secondary floodplains and terraces. For transect one, cross-section area under the low elevation datum changed from 337 m^2 in 2012 to 407 m^2 in 2021, revealing an overall evacuation of sediment from the low flow channel between these two time

periods. In contrast, the form and elevation of secondary floodplain features to the left of the low-flow channel appeared to have changed little between 2012 and 2021 (Fig. 12).

Competition from Non-Native Plants

With regard to controlling non-native plants as a complicating factor for Restoration Site A, propagules of non-native plants present upstream will enter the site and likely establish on suitable surfaces throughout Horseshoe Reservoir. Criteria for managing these species should be developed (see Section Five). Given our current understanding of biophysical conditions and trends at Restoration Site A, an appropriate long-term objective for managing non-native plants at Restoration Reach A may be to focus more on managing non-native vegetation at appropriate levels versus their complete elimination. That noted, there may be specific invasive species that SRP may want to keep a close eye on and eliminate completely if found on site. A 'nip in the bud' approach to prevent the species from becoming a future nuisance. For example, the establishment of *Ailanthus altissima* and *Arundo donax* are potential candidates in this regard.

Site Restoration Objective

With the above discussion in mind, the recommended long-term goal for Restoration Site A will be to foster a diverse riparian plant community where no one particular plant species dominates. To accomplish this goal, proposed restoration actions at Restoration Site A are to: (i) Monitor biophysical conditions to quantify changes in channel morphology, water availability (with depth to saturated soils being particularly important), and riparian vegetation in response to changes in dam management; (ii) Conduct targeted and strategic revegetation only if such is deemed important to fostering the establishment of native bottomland plant communities; and (iii) Manage non-native vegetation as deemed necessary to foster increased distribution and extent of native bottomland habitat.

[Figure 13. Idealized digital rendering of the restoration goal at Site A.]

Based on current understanding of site conditions, it is proposed that actions two and three be targeted and limited, with management at Restoration Site A emphasizing an overall passive restoration response that focuses an adaptive management (or adapted restoration response) that is informed by monitoring. If actions two and three are deemed appropriate and helpful, the intent is to conduct those actions at small spatial scale that could boost the extent and distribution of desired native plants along this reach. For example, if revegetation is considered appropriate, revegetation could focus on establishing pockets of obligate and non-obligate riparian species. And, if deemed necessary, invasive plant management efforts might focus on reducing the extent and distribution of *T. ramosissima*, *Arundo donax*, *Ailanthus altissima*, cocklebur (*Xanthium strumarium*), kochia (*Kochia scoparia*) and other species that have demonstrated a propensity to establish along the lower Verde River and compete with native plants (see Appendix 1).

A summary of proposed long-term restoration goal for Restoration Site A and factors that may complicate realizing this goal is provide in Table 1.

Table 1. Summary of long-term restoration goal and complicating factors for Restoration Site A.

Proposed Restoration Goal	
Mix of obligate and non-obligate native plant communities where no one species dominates with emphasis on realizing this restoration goal via passive versus active management.	
Complicating Factors	
Low water availability	With run-of-river management, it is likely that the frequency and duration that Restoration Site A will be inundated will decrease with consummate impacts on water availability. However, such will likely strengthen natural processes and dynamics at this site, which will have overall positive impacts on native flora and fauna.
Flood scour	With reduced inundation by impounded pool waters, natural flow dynamics will be strengthened. Flood scour will occur (along with deposition), which is natural and beneficial. As noted previously, at Restoration Site A and other sites where native bottomland regeneration is likely when run-of-river management is implemented, SRP may want to take a patient, non-active restoration approach that focuses on monitoring biophysical response over the implementation of active restoration actions.
Soil salinity	Not a concern. Even if high soil salinity occurs in parts of this restoration site, levels will likely be reduced in a run-of-river management future that will reduce the frequency and duration that Restoration Site A is inundated.
Prolonged inundation	Much less a concern at this site as compared to downstream restoration sites, particularly if run-of-river management becomes the norm.
Competition from non-native plants	The strengthening of natural flow dynamics should provide physical conditions favoring the establishment of native plants. Monitoring and targeted management is warranted.

Proposed Next Steps
i.   Additional targeted site reconnaissance and analysis of aerial photograph is warranted.
ii.   Establish a thoughtful, realistic monitoring program to quantify biophysical change at this site. Ideally, monitoring sites should be established prior to when run-of-river management becomes the norm.
iii.   Conduct targeted revegetation and invasive control actions only if deemed necessary.

RESTORATION SITE B
Location and Restoration Objectives

The backbone of Restoration Site B is essentially the Verde River channel downstream of Chalk Mountain to the mouth of Lime Creek that has incised sufficiently into reservoir alluvium to capture the majority of Verde River flow during low flow periods (Fig. 14).[9] However, the overall spatial footprint of Restoration Site B is much larger than just the low flow channel, encompassing a significant portion of the central portion of Horseshoe Reservoir where conditions of water availability, protection from flow scour, and the frequency and duration of inundation by the reservoir pool potentially provide favorable conditions for the establishment and persistence of obligate riparian plants (Fig. 14).

The current position of the low flow channel that constitutes the backbone of Restoration Site B hugs the western shoreline of the reservoir, extending from just downstream of where the reservoir valley widens significantly south of Chalk Mountain to just north of the mouth of Lime Creek (on the western shoreline of the reservoir). From the standpoint of restoring native obligate riparian plants, Restoration Site B is attractive given the presence of willows along the past position of the low flow channel when it hugged the eastern shoreline of the reservoir.

As underscored in *Section Three - Central Challenges to Establishing Native Plant Communities Within the Horseshoe Reservoir Study Area*, water availability during the dry, hot months of May and June when average Verde River flow is but a trickle is a key challenge to establishing native obligate riparian plants. The trickle of water through the low-flow channel during these months is likely an essential element that permits the maintenance of the saturated soil zone at elevations sufficiently shallow to allow access by the shallow root systems of obligate riparian plants.

Also discussed in Section Three, the riparian stability continuum needs to be taken into account as part of identifying sites within an active bottomland environment that have characteristics suitable for the establishment and long-term persistence of obligate riparian plants. Water availability and vulnerability to flood scour are two central aspects of the riparian stability continuum. Obligate riparian seedlings may be able to establish and persist near the low flow channel of Site B given higher water availability conditions that allow them to get through the hot, dry season. Yet, long-term persistence may be thwarted if seedling establishment in high water availability are scoured out by the next food event. An important challenge for establishing

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[9] The limited channel capacity of these features means that discharge magnitudes probably not much greater than a two-year event will exceed channel capacity, forcing flow outside the thalweg and across the surrounding and relatively flat reservoir surface.

native bottomland habitat at Site B is identifying areas that provide suitable water availability as well as some measure of protection from flood scour.
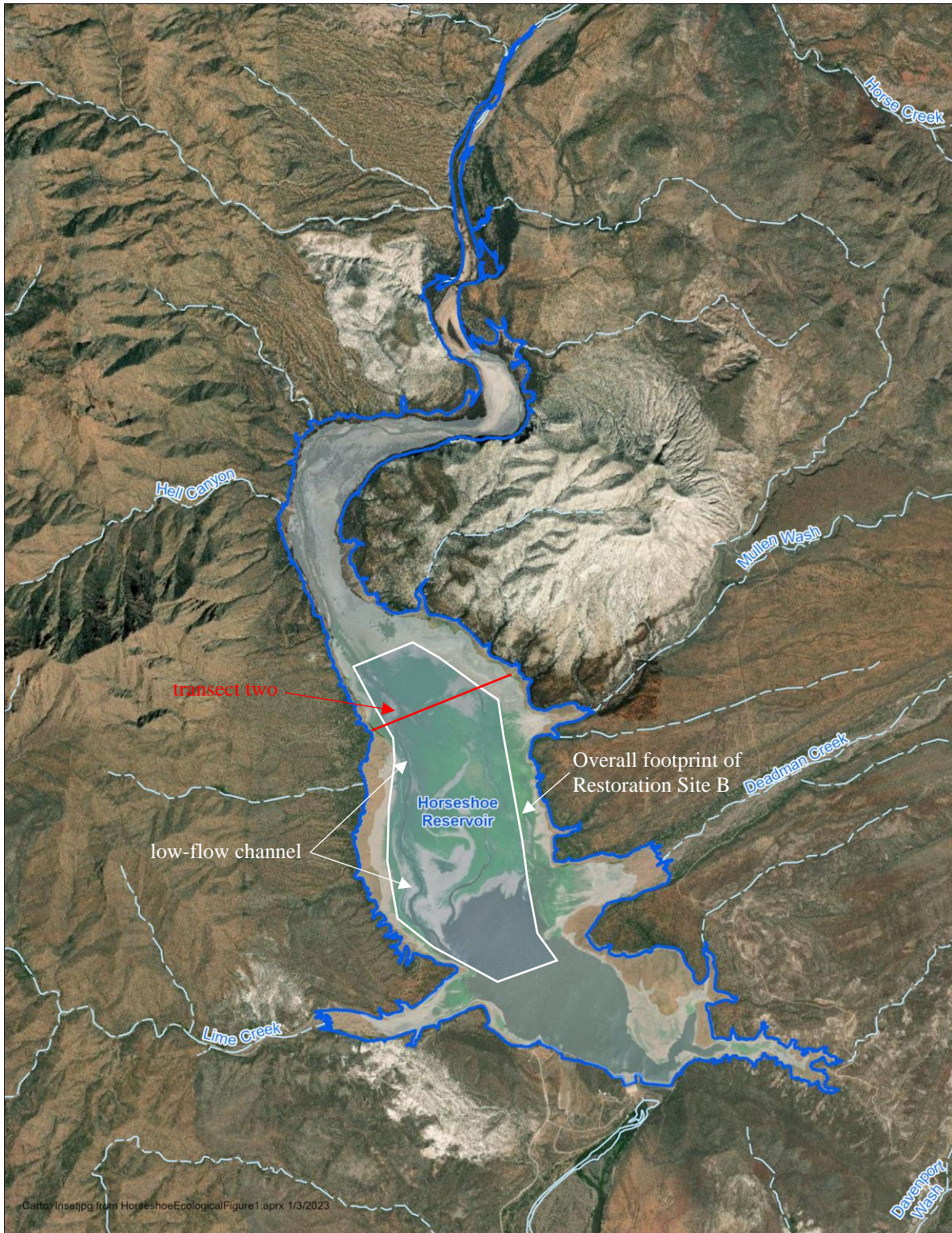
Figure 14. Image of Horseshoe Reservoir showing overall footprint of Restoration Site B and location of transect two. The backbone of Restoration Site B is the low flow channel.

In this regard, the fact that willows naturally established within the footprint of Restoration Site B is important. The take home point being that, even under past management of Horseshoe Dam, sweet spots along the riparian stability continuum were naturally 'found,' with willows establishing and persisting for almost two decades. This is borne out by examining the locations of past low flow channels within Horseshoe Reservoir and noting willow establishment along them. Active low flow channels of the recent past appear as ghost relics that trace the path of past channel migration across the reservoir valley in response to processes of sediment evacuation and deposition during moderate to high Verde River flow events (Fig. 15). Once a given channel thalweg (or active low-flow channel) has incised sufficiently into valley sediments to capture flow, it will receive the majority of Verde River low flow until alluvial depositional processes occur to impede flow, forcing abandonment and the formation of an entirely new low flow channel. Such a scenario likely occurred during high flow events of 2008 and led to the quasi-abandonment of the low-flow channel on the eastern side of the reservoir to the present position of the low-flow channel on the western side of the reservoir (Fig. 15).

Figure 15. A comparison of aerial photography between 2002 and 2008 at Restoration Site B that shows the formation of a sediment plug that likely impeded flow in the eastern Horseshoe Reservoir low-flow and led to establishment of the current low-flow channel that heads due south. The establishment and persistence of trees along the channel is clearly demarcated in the 2008 photograph (images provided by SRP Cartographic & GIS Services).

In the context of considering the riparian stability continuum for Site B, it is not surprising that obligate riparian trees were able to establish when the low flow channel was on the eastern side of the reservoir. From the standpoint of water availability, the trickle of Verde River flow through the low flow channel during May and June (no matter where its location within the reservoir proper) was likely a key factor that maintained the soil saturated zone at appropriate

elevations for obligate riparian plants. From the standpoint of flow scour, the willows that established along the eastern shoreline of the reservoir valley are protected from the full brunt of Verde River high flow energies given their location on the leeward side of Chalk Mountain.

When the Verde River experiences a high magnitude flow event at a time when the Horseshoe Reservoir pool is well below the conservation pool elevation, the high flow energy vector is due south with flow energies dissipating considerably when a Verde River flood event enters the reservoir proper south of Chalk Mountain and spreads out. Of course, flow energies will also dissipate dramatically once the reservoir pool fills sufficiently to intersect flow. Nonetheless, scouring high magnitude flow events likely occurred frequently in the past even under non run-of-river management and is likely one reason why willows successfully established and persisted along the low flow channel when it was located on the eastern side of the reservoir (and thus protected from scouring flow energies) and have not established to an appreciable extent along the current position of the low flow channel, which now hugs the western shore of the reservoir (and, as such, lies immediately along the vector of high flow energies). Obligate riparian seedlings that established in the Spring along the current position of the Verde River low flow channel within the reservoir are likely scoured out by the next high flow event of sufficient magnitude and energy to mobilize sediment.

As SRP considers the potential for natural and/or artificial establishment of obligate riparian plants within the footprint of Restoration Site B, there seems to be two main paths forward. First, is to follow a similar course of action as for Restoration Site A and monitor biophysical change before and after run-of-river management is initiated. In this vein, 'sitting back' and evaluating biophysical responses under run-of-river management would be emphasized over the implementation of active management actions. This is certainly a viable path forward. Obligate riparian plants naturally established within the footprint of Restoration Site B in the past and will likely do so again. In this regard, it is important to note that the establishment of willows along the low-flow channel under past flow management occurred in a context where the morphologic characteristics of the low-flow channel appeared to have changed little between the years 2012 and 2022 (Fig. 16). Morphologic change of low flow channels particularly within the northern portion of Site B is likely to become more dynamic – more natural - as the frequency and duration that Site B is inundated by the reservoir pool is reduced under run-of-river management. How this impacts the establishment and persistence of obligate riparian plants is an open question. Though, as with Restoration Site A, natural regeneration of native species is likely to be fomented by a return to more natural flow dynamics. In summary, placing little emphasis on active management with much more attention on monitoring biophysical[10] response of Restoration Site B before and after run-of-river management is initiated is certainly a viable option.

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[10] Although biophysical conditions are emphasized here, the chemical part of the riparian stability continuum should not be ignored, particularly with regard to the potential that portions of Site B may have elevated soil salinity levels. However, if that is the case, a reduction of soil salinity levels would be expected under run-of-river management with a return to a more natural flow regime having great potential to flush accumulated salts. Regardless, targeted in-situ measurement of soil salinity may be worthwhile particularly in areas where pilot revegetation efforts are being contemplated.

A second path or option for SRP with regards to Restoration Site B could emphasize active management to a much greater degree, particularly in the form of a robust monitoring program along with conducting targeted artificial 'pilot' revegetation efforts. The central aim of both actions would be to improve understanding of reservoir biophysical conditions under run-of-river management that would allow a more informed foundation for identifying parts of Restoration Site B that offer conditions most conducive for the long-term viability of obligate riparian plants. As already noted above, we know that conditions within the Site B's footprint support the establishment and persistence of obligate riparian plants. However, we also know that biophysical conditions have changed to a point where ecohydrologic thresholds have been crossed or compromised that not only have negated further natural regeneration but have led to the demise of mature willow trees (Fig. 17). Where are the current sweet spots for establishing obligate riparian plants and how might they be affected when run-of-river management is implemented are key questions that SRP may want to address head-on as part of this second option.
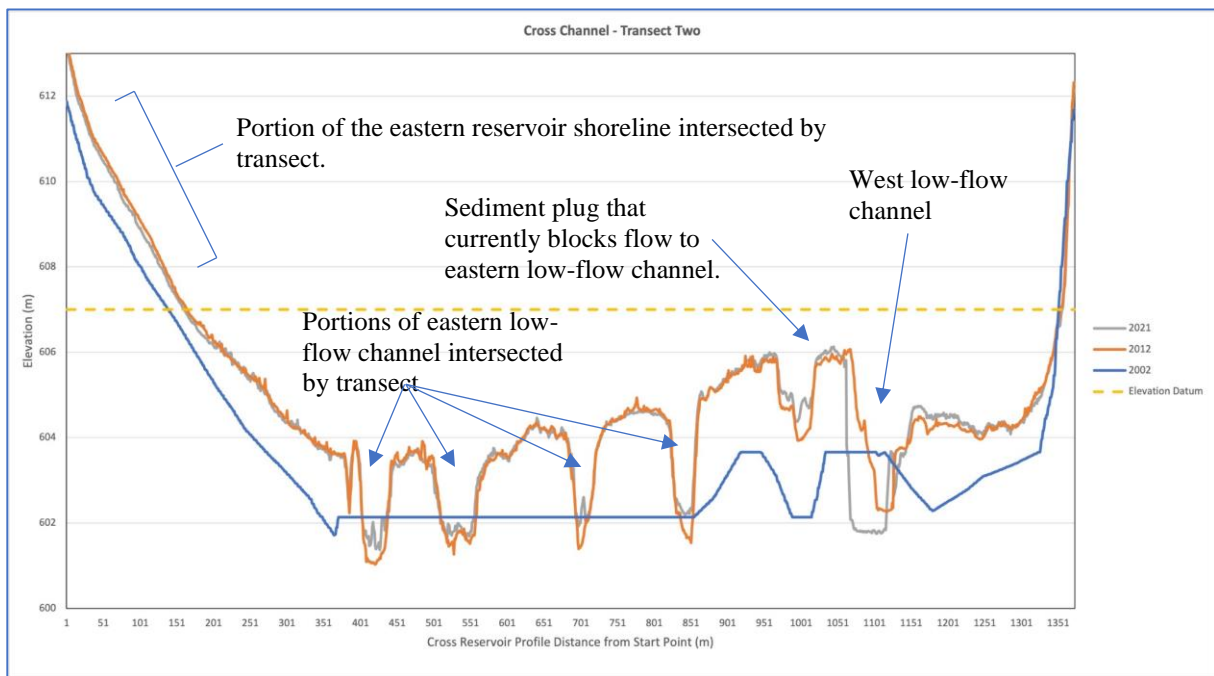
Figure 16. Graph of elevation change across transect two (see Figure 14 for transect location), which extends west to east across the reservoir at the northern portion of Restoration Site B. In this location, the transect cuts across both the current low-flow channel on the western side of the reservoir and multiple parts of the former low-flow channel on the eastern side of the reservoir. Elevation data were developed from remote LiDar (2012 and 2021) and multispectral imagery platforms (2002). Note only subtle morphologic changes between the years 2012 and 2021 (see also Table 2).

Table 2. Summary of channel cross-sectional area under elevation datum (see Figure 16 for elevation datum) at Restoration Site B and percent of points along and outside the channel with vegetation of 0.3 m or greater in height. The large difference in percentage of vegetation along the low-flow channel and outside the channel (comparison of rows two and three for years 2012 and 2021) indicate the importance the low-flow channel has in providing conditions suitable for the persistence of obligate riparian vegetation. The dramatic decline of vegetation along the low-flow channel between 2012 and 2021 (row 2) may be due to the formation of the sediment plug, which likely shunted most flow during May and June to the current low-flow channel that lies along the western shore of Horseshoe Reservoir.

Transect Two Parameter	2002	2012	2021
Channel (or Reservoir) Cross-Section Area Under Elevation Datum (m2)	na	3,359.7	3,386.6
Percent of points w vegetation > 0.3m in height along the low-flow channel within Site B (376m - 1201m from starting point)	na	24.5	8.5
Percent of points w vegetation > 0.3 m in height outside the low-flow channel (200m - 360m from transect starting point)	na	0.6	0

Figure 17. Photograph of dead willows snags within the footprint of Site B near the mouth of Mullen's Wash. These trees likely succumbed from the combined impacts of desiccation (possibly as a result of the sediment plug that blocked low flow to this portion of the reservoir) and prolonged inundation.

A robust monitoring program could include the establishment of a series of piezometers that will allow measurement of shallow groundwater elevations that would improve understanding of how shallow groundwater elevations within the reservoir vary with Verde River flow as well as spatially with-in the reservoir (from north to south as well as with increasing distance from the low flow channel). In addition, modeling of how run-of-river management will impact surface water elevation variation of the reservoir pool behind Horseshoe Dam could also be emphasized as part of a more in-depth investigation that would inform an effective restoration response.

In addition to implementing a robust monitoring program, SRP should consider conducting targeted pilot revegetation as part of this second option. As is emphasized in *Section Five - Information Gaps and Suggested Next Steps*, conducting pilot revegetation efforts and monitoring results of such efforts has the potential to provide SRP invaluable biophysical and non-biophysical information that can significantly inform the realities of conducting such on-the-ground efforts at larger spatial scales. If pilot revegetation is pursued at Restoration Site B, it is recommended that the focus be on establishing a series of patchy, small-scale plantings after run-of-river management has been initiated (Fig. 18).

[Figure 18. Digital graphic renditions of Restoration Site B from planar and cross-section view.]

In this vein, pilot revegetation would focus on using pole plantings to establish pockets of willows that emphasize coyote willow (*Salix exigua*) over (*Salix gooddingii*) (10 coyote willows for every Goodding willow), given coyote willow's ability to survive prolonged inundation as well as to layover and survive high magnitude flow events. Certainly, other species could be considered and included but willows are emphasized here given ease of planting (i.e., poles or branches of willows can be collected from nearby sites and planted relatively easily). The footprint of each revegetation pocket would be small in size (less than 200 m^2) consisting of 50 to 100 poles with revegetation pockets extending along a west to east transect line that ranges from the edge of the current active low flow channel toward the reservoir shoreline (Fig. 18). The overall strategy is for the revegetation pockets along any particular west-to-east transect line to cover as much of the riparian stability continuum as possible.

High mortality is to be expected with desiccation, flood scour and inundation taking their toll. But planting along the stability continuum increases likelihood that one or more sweet spots will be planted that are characterized by key physical attributes conducive to establishment and growth of native bottomland species. A successful patch of planted vegetation along the continuum (i.e., along a west to east transect heading away from the current position of the low-flow channel) can profoundly inform and improve the effectiveness of a larger scale revegetation effort. It is also important to note that the establishment of even a small percentage of trees that are planted can augment native plant seed fall that can produce long-term ecological benefits, particularly with regard to fomenting natural recruitment of native species. A hundred trees surviving in the long-term out of a thousand planted could provide significant ecological benefit.

Another potential benefit of conducting artificial revegetation at Site B (at pilot scale in the near-term and at large scale in the future if pilot efforts prove successful) has to do with the potential response of invasive plants to run-of-river management. As noted previously, run-of-river management will likely reduce the frequency and duration that interior parts of the reservoir area (i.e., much of Restoration Site B) are inundated by the reservoir pool. As this occurs, strong regeneration by a variety of invasive plants is expected. Species such as *Sesbania herbacea*, *Amaranthus palmeri*, *Cynodon dactylon*, *Xanthium strumarium*, in addition to other invasive plants that are part of seed base of the greater Horseshoe Reservoir ecosystem will come to dominate reservoir surfaces that are no longer frequently inundated by the reservoir pool for extended periods of time. Although such an invasive plant regenerative response will provide poor quality wildlife habitat and likely preclude (or at least hinder) natural regeneration of many native bottomland plants, there will be benefits, including the ability of a dense vegetative cover to reduce dust emissions from reservoir surfaces that would otherwise be largely exposed to the elements. Regardless, there will be significant added benefits if pockets of native vegetation can be established in what will likely be a 'sea' of invasive plants, including the augmentation of native seed fall as well as shading out invasive plant response in areas where native plants are successfully established.

The above discussion brings up one question that is highlighted further in *Section Five – Information Gaps and Next Step*s. Can SRP manage Horseshoe Dam with gates wide open for an extended period of time as part of subsequent phases of the Horseshoe Reservoir Restoration Study? In other words, in the near future, would there be storage capacity in Bartlett Reservoir to allow the operation of Horseshoe Dam with gates wide open for extended periods of time

(months to possibly more than a year) before run-of-river management is adopted as the 'official' management protocol? Related to this question is the rate at which Horseshoe Reservoir draws down when there is significant runoff from the Verde watershed. The question being, does Horseshoe Dam release water at a high enough rate with "gates wide open" to shorten the inundation time for the reservoir area in Restoration Site B (looking ahead, this question is also pertinent to Site F, but from the other way around, asking if Horseshoe Dam gates could be closed during key times to retain water at that site)? Whether future data are collected as part of a monitoring program (e.g., data of shallow groundwater elevations from piezometers) or pilot revegetation, or both, collecting data that reflect biophysical conditions under run-of-river management is needed and would be most helpful to understanding reservoir biophysical conditions under run-of-river management.

Advantages and Drawbacks
As we conclude this section with selected advantages and drawbacks to Restoration Site B, it is important to note that of all the potential restoration sites presented in this report, Site B is the only one identified that encompasses what is currently considered the interior of Horseshoe Reservoir. All the other sites, with possible exception of the lower reaches of Restoration Site A - which considers the entire active bottomland environment of the Verde River at that location - focus on the reservoir shoreline. This distinction (reservoir interior versus reservoir shoreline) will certainly carry important differences in biophysical characteristics that, in turn, will profoundly influence the types of native bottomland plant communities that can establish and be viable in the long-term under run-of-river management. Another important distinction between Site B and the other restoration sites is the current level of understanding of biophysical conditions. During the course of this one-year study, visiting the other sites was possible. In contrast, the grand majority of Site B was under water. Although expert opinion and conjuncture are an inherent part of the conceptual stage of every restoration effort, the information and insights gained via a first-hand field visit cannot be overstated. As such, visiting Site B in the near future during dry periods should be a priority.

The proposed restoration objective for Restoration Site B and potential challenges toward realizing the proposed restoration objective are summarized in Table 3.

Table 3. Summary of long-term restoration goal and complicating factors for Restoration Site B.

Restoration Goal	
Establishment of a patch work of native obligate riparian plants within the interior of reservoir via natural and artificial means.	
Complicating Factors	
Low water availability	Given a future climate that is hotter and drier, identifying sites with conditions of water availability suitable to the establishment of obligate riparian plants is an inherent challenge. That noted, specific parts of Restoration Site B may offer opportunities from the standpoint of water availability, particularly in areas near the low-flow channel where shallow groundwater elevations can be maintained above threshold levels by low flow during the hot, dry season.

Flood scour	As noted previously, finding the sweet spot in the riparian stability continuum within the footprint of Restoration Site B with suitable water availability and protection from flood scour will be challenging. Installing piezometers in targeted areas to monitoring shallow groundwater elevations and conducting pilot revegetation will greatly inform where native obligate riparian plants can most effectively be established.
Soil salinity	Given the establishment of willows at this site in the past, elevated soil salinity does not appear to be a major issue. In addition, run-of-river management with assumed ramification of establishing more natural flow dynamics will make the accumulation of soil salts an even less concern.
Prolonged inundation	Particularly with run-of-river management in effect, the likelihood that prolonged inundation will reach elevation and duration threshold levels for native obligate riparian plants will be less of a concern than in the past. Modeling how reservoir pool elevations (per discussion in Section Five) will be impacted under run-of-river management will provide helpful insights as to where prolonged inundation will likely still occur at high frequencies and duration.
Competition from non-native plants	Strong establishment of a variety of invasive plants is to be expected with reduced frequency and duration of inundation by the reservoir pool under run-of-river management. Implementing targeted revegetation with native overstory species could help. Monitoring vegetation response as run-of-river management is put into effect should be conducted, allowing targeted management of undesirable plants if such is deemed necessary.
Proposed Next Steps	

   i.   Conduct additional targeted site reconnaissance when the elevation of the reservoir pool is low and portions of Site B are exposed.
   ii. Establish a thoughtful, realistic program to install a series of piezometers to monitor shallow groundwater elevations and how elevations vary both spatially and temporally.
   iii. Conduct targeted pilot revegetation (per previous discussion in this section).
   iv. Model how variation in reservoir pool elevations will be impacted under run-of-river management (with Horseshoe Dam gates wide open the grand majority of the time).

RESTORATION SITE C
Location and Objective
Restoration Site C is located along the eastern shoreline of Horseshoe Reservoir upstream of the mouth of Mullen's Wash (Figs. 9 and 19). The elevation of the shoreline increases in an easterly direction, with surfaces of lower elevation toward the central portion of the reservoir and surfaces of higher elevation closer to surrounding hills, giving an overall range in elevation between 608 m (1,995 ft) and 612 m (2,007 ft) (see also cross-reservoir transect shown in Figure 12, which intersects a portion of Restoration Site C). At almost 20 ha (50 acres) in area,

Restoration Site C is the largest contiguous footprint of all the restoration sites proposed in this study. Daily surface elevation data of Horseshoe Reservoir pool from 2001 to 2021 indicate that the majority of the surfaces that comprise Restoration Site C were underwater 12% of the time during that 20-year time period.

Figure 19. Aerial photographs of the southern portion of Restoration Site C just north of mouth of Mullen Wash. The majority of this site was inundated by impounded waters behind Horseshoe Dam about 12% of the time (as depicted in aerial photograph of June 2010 (left)). The reservoir shoreline that comprises the restoration site is clearly shown in aerial of May 2013 (right).

With dramatic swings between being inundated by impounded waters and being left high and dry after pooled waters had retreated, Restoration Site C is a harsh site for desirable native plants to establish under current reservoir management operations (Fig. 20). On one extreme, its relative high elevation along the shoreline of Horseshoe Reservoir likely made the soil saturation zone too deep for the shallow root systems of obligate riparian plants to access. On the other, the frequency and duration that this site was under water may have precluded the establishment of other desirable native plants, such as mesquite, that are not tolerant to prolonged periods of inundation. If we assume that this site will be inundated much less frequently under run-of-river management, there may be opportunities for establishing a non-obligate riparian plant community made up of *Prosopis* spp., *Celtis reticulata*, *Acacia* spp., *Chilopsis* sp., *Lycium* spp., *Atriplex* spp., and other bottomland species that, though part of the active bottomland environment, are adapted to bottomland surfaces that are inundated at less frequency and have less water availability than primary floodplains or other surfaces suitable for obligate riparian plants. Additionally, this type of vegetation/habitat may serve as mitigation for other impacts, such as 404, or buffer lands in response to ESA recommendations. The main point being that bottomland habitat restoration in whatever form that makes sense ecologically should not be dismissed just because it doesn't directly support a listed species.

Advantages and Drawbacks

There are two attributes that make Restoration Site C intriguing from the standpoint of establishing native bottomland communities. First, as mentioned above, this is a reservoir shoreline site that under past management experienced dramatic annual fluctuation in water levels, fostering the unvegetated bathtub ring mentioned in Section Three that is often observed along reservoirs in arid climates. If future run-of-river management at Horseshoe Reservoir reduces the magnitude of water surface elevation swings, shoreline surfaces like those at Restoration Site C are likely to become more suitable for native vegetation communities (in addition to non-native) (Fig. 21). Understanding such key site characteristics as soil salinity, soil physical characteristics, vegetation, how depth to saturated soils varies during the course of the year as well as how saturated soil elevations and site surface morphology will change under run-of-river management, amongst other factors is important to identifying the types of native plants appropriate for the site. Regardless, there is much inherent restoration potential given that a key impediment to the establishment of non-obligate riparian plants – frequent and prolonged inundation - will likely be diminished or potentially eliminated as a stressor at this site (Fig. 22).

Figure 20. Photograph of Site C surfaces just upstream of the mouth of Mullen's Wash. Dead willows scattered in a sea of dead *Amaranthus palmeri* underscore the harshness of an environment affected by frequent and prolonged inundation by the Horseshoe Reservoir pool as well as by periods that leaves these surfaces high and dry for extended periods of time.

Second, Restoration Site C is essentially a fluvial-dominated delta environment that receives water, sediment, nutrients and energy fluxes from four small tributaries and one larger tributary – Mullen Wash. These tributaries are ephemeral and hydrologically flashy, producing high-energy discharges of brief duration during periods of prolonged and/or intense precipitation. There is

growing recognition of the vital importance of such cross-ecosystem fluxes of energy and materials between wet (in this case, the Verde River bottomland environment) and dry ecosystems (ephemeral washes) for their sustainable management (Anderson et al. 2008, Bartels et al. 2012). The portion of Restoration Site C in close proximity and at the receiving end of flow energies emanating from these tributaries are likely scoured during the rising limb of a high magnitude flood event, with aggradational processes dominating on the descending limb of the flood hydrograph. In contrast, aggradational process likely dominate on surfaces further downstream of tributary mouths as well as on surfaces just upstream and downstream of tributary outflows.

Figure 21. Two photographs showing surfaces of high potential for the establishment of native bottomland plant communities at Site C. Photograph on the left is just north of the mouth of Mullen's Wash and shows two potential planting surfaces that differ in elevation of just over one meter. The lower elevated surface (with water indicating the elevation of the reservoir pool at the time the photo was taken) currently supports *Salix exigua* (coyote willow) and may so in the future even under run-of-river management. Higher elevated surfaces may be conducive to the establishment of native non-obligate riparian plants. Dead willows (likely *S. gooddingii*) in the background on the photo on the right appear established in the past 'sweet spot' of the riparian stability continuum. At least for a brief period of time (maybe five years) before their demise, these surfaces supported willow establishment with characteristics that provided protection from flood scour while also providing sufficient water availability. Mapping these surfaces should be a priority to inform where native bottomland plants could be successfully established in the future.

In natural conditions prior to dam construction, a north to south hike along the longitudinal axis of Restoration Site C would likely have been topographically and vegetatively diverse, with mature and dense vegetation established on higher elevated and more stable aggradational surfaces contrasted with young and patchy vegetation on surfaces that routinely experience tributary outflow scouring flows. The plant community that dominated Restoration Site C was likely of similar composition to the xeroriparian forests that currently occur in the bottomland environments of Deadman's Wash, Mullen Creek and Lime Creek where access to surface water

depends on short-lived and unpredictable rainfall run-off events but where deeper groundwater may be present. In general, such xeroriparian forests are composed of upland plants that are adapted to drought and other harsh conditions) and often include such species as mesquite (*Prosopis* spp.), catclaw acacia (*Acacia greggii*), desert willow (*Chilopsis linearis*), and paloverde (*Parkinsonia* spp.) (Lowe 1961; Johnson and Lowe 1985; Johnson, Bennett, and Haight 1989; Beauchamp and Shafroth 2011). In a nutshell, prior to the construction of Horseshoe Dam (and the subsequent buffering impacts of pooled waters behind Horseshoe Dam) the surface of Restoration Site C was likely dynamic and biophysically diverse with tributary inputs frequently impacting a variety of surface biophysical characteristics (Fig. 22).

[Figure 22. Digital rendering of what may be a realistic restoration option for Restoration Site C. Lower elevated surfaces that constitute a small portion of the site may offer opportunities to establish native obligate riparian plants with the grand majority of the site being conducive to establishing a xero-riparian community that is better adapted to dry, hot conditions]

If run-of-river becomes the future management norm, the frequency and duration that Restoration Site C will be inundated by waters impounded behind Horseshoe Dam will likely decline along with the buffering effects that inundation has on tributary outflows. From the standpoint of restoration, the return of natural hydrology cycles is of great benefit to native flora and fauna. It will be fascinating to observe biophysical change at this site once run-of-river management is implemented. Indeed, what we are advocating in the near-term is to develop a realistic (from standpoint of funding, equipment personnel needs) and thoughtful monitoring program for this site that allows quantification of change and an effective adapted management response that may include targeted revegetation with appropriate native species and targeted management actions to reduce the extent and distribution of non-native plants (Fig. 23 and Table 4).

Figure 23. Photograph of a part of Restoration Site C just north of the mouth of Mullen's Wash. One *Sporobolus wrightii* (giant sacaton) has established in the midst of a dense matt of dead *Amaranthus palmeri*, indicating one native species that could be a viable component of future native bottomland plant establishment.

Table 4. Summary of long-term restoration goal and complicating factors for Restoration Site C.

Restoration Goal	
A xeroriparian forest composed of such nonobligate riparian plants as mesquite (*Prosopis* spp.), catclaw acacia (*Acacia greggii*), desert willow (*Chilopsis linearis*), and paloverde (*Parkinsonia* spp.) is established on much of Site C, with lower elevated surfaces of greater water availability potentially supporting *S. exigua*.	
Complicating Factors	
Low water availability	As with other restoration sites, prolonged periods of drought will certainly impact native plant communities that ultimately establish on Restoration Site C. That noted, species such as *Prosopis* spp.*, Acacia* spp.*, Parkinsonia* sp., *Sporobolus wrightii*, others are drought tolerant and capable of surviving drought periods. Focusing restoration attention on more drought tolerant species addresses the low water availability challenge; at least from stand point of making it less of a challenging factor than when obligate riparian and wetland plant communities are being considered.
Flood scour	Given location of Site C on the eastern shore of the reservoir, scour as a result of high magnitude flows from the Verde River is not a significant concern. However, surfaces vulnerable to flood scour from Mullen Wash may become more vulnerable with the decline in the frequency and duration of reservoir pool inundation. Such a return of natural flow dynamics is welcome and a natural part of this delta environment. Mapping Site C surfaces that are less prone to the impacts of flood scour should be a priority (per Figure 21).
Soil salinity	Although soil salinity levels could be elevated as a result of past inundation, such is not a significant concern given that (i) most xeroriparian plants are more salt tolerant than their obligate riparian counterparts; and (ii) excess soil salts are likely to be

	regularly flushed out of this area with the decline in inundation frequency by impounded waters behind Horseshoe Dam.
Prolonged inundation	The important and central biophysical assumption for Restoration Site C is that run-of-river management will reduce frequency that this site is inundated, which is a key factor to the potential for reestablishing native non-obligate riparian plant communities.
Competition from non-native plants	The establishment of invasive, early successional plants is likely to be a challenge at this site. Parts of the site are already dominated by *Amaranthus palmeri* and *Sesbania herbacea.* The extent and distribution of these and other invasives are likely to become greater with the retreat of the reservoir pool under run-of-river management. Monitoring of biophysical conditions is encouraged with targeted management of invasive plants possibly being a priority in context of improving establishment of native and non-native species (see discussion in Appendix A).
Proposed Next Steps	

  i. Conduct additional site reconnaissance to map current vegetation and morphologic conditions and address knowledge gaps associated with this site.

  ii. Conduct additional analysis of aerial photography to better understand past inundation frequencies and vegetation response.

 iii. Establish a thoughtful, realistic monitoring program to gauge vegetation response after run-of-river management is implemented.

 iv. Model how variation in reservoir pool elevations will be impacted under run-of-river management (with Horseshoe Dam gates wide open the grand majority of the time).

  v. Conduct spot pilot revegetation actions to test viability of establishing a diverse suite of native bottomland plants.

RESTORATION SITE D
Location and Objective

Restoration Site D encompasses fluvial-dominated surfaces along the eastern shoreline of the reservoir just north and south of the mouth of Deadman's Wash that range in elevation from 615.5 m (2019 ft) to 617.1 m (2024 ft) (Figs. 9 and 24). Daily surface elevation data of the Horseshoe Reservoir pool from 2001 to 2021 indicate that the majority of the surfaces that comprise Restoration Site D were underwater 5% of the time during that 20-year time period.

Figure 24. Aerial photographs indicating location of low-lying shoreline surfaces just north and south of the mouth of Deadman's Wash that comprise the majority of Restoration Site D. A comparison of aerial photography between June 2010 and October 2021 underscore frequent inundation of these surfaces under past management of Horseshoe Dam. The red circle in the 2021 aerial photograph indicates position of the cluster of *S. gooddingii*, which is highlighted further in Figure 26.

As with Restoration Site C, the shoreline surfaces that are at the heart of restoration options at Restoration Site D are impacted by dramatic swings in hydrology under current management of Horseshoe Dam that both inundate these surfaces for extended periods of time and leave them high and dry when the reservoir pool retreats during the hot, dry season. Although the majority of the surfaces that comprises Restoration Site D were under water less frequently than those of Restoration Site C, the frequency of inundation nonetheless seems likely to have been at thresholds sufficient to thwart the establishment of a xeroriparian (or non-obligate riparian) plant community. As with the uplands that surround much of lower Mullen's Wash, the uplands surrounding lower Deadman's Wash support a diverse desert scrub plant that likely would be able to establish on nearby lower elevated surfaces if not for the frequent inundation by the Horseshoe Reservoir pool.

At the same time, the routine retreat of the reservoir pool during the hot, dry season left these same surfaces high and dry for sufficient time periods that negated the establishment of an obligate riparian plant community. It is important to note that despite the dramatic swings in the elevation of the reservoir pool that were typical of past management, *S. gooddingii* were able to establish on lower elevated surfaces just west of the mouth of Deadman's Wash (Figs. 25 and 26). It is difficult to determine at this point whether the establishment of these willows was fostered because of or despite the dramatic pendulum hydrologic swings between prolonged inundation and desiccation. Regardless, it is expected that the frequency that Site D surfaces will be inundated would be significantly less under future run-of-river management and thus make the potential for establishing obligate riparian plants at this site more of a challenge.

The central objective of future restoration efforts at Site D would be the establishment of a non-obligate riparian plant community on shoreline surfaces that were frequently inundated in the past. Plant diversity would likely consist of many of the same plant species that are currently establish on surrounding upland surfaces: *Prosopis* spp., *Parkinsonia* spp., *Simmondsia chinensis*, *Celtis* spp, amongst others. The fact that *Salix* spp. have established at Site D in the past (albeit on surfaces lower in elevation than shoreline surfaces) highlight the potential that restoration efforts could include *Salix* spp. But the emphasis for restoration at Site D under run-of-river management would be xero-riparian (Fig. 27). Targeted artificial plantings of native plants would help spark natural regeneration and offer a means to push back on the establishment of an invasive plant community, which is expected to occupy Site D surfaces and compete with native plant establishment.

Figure 25. Photograph of Restoration Site D reservoir shoreline surfaces just to the south of the mouth of Deadman's Wash (middle portion of the photograph). Dramatic swings in water availability - between frequent and prolonged periods of inundation and pool retreat – have left these surfaces relatively free of vegetation.

Figure 26. Photograph of a mature *S. gooddingii* near the mouth of Deadman's Wash provide evidence that obligate riparian trees were able to establish and persist at this site for numerous years. The dead willows surrounding the one remaining live willow likely succumbed as a result of desiccation when reservoir pool retreat was sufficiently dramatic to drop the zone of soil saturation below the root zone. Invasive, annual *Amaranthus palmeri* surrounds the willows.

Advantages and Drawbacks

Similar to Restoration Site C, a better understanding of such key site characteristics as soil salinity, soil physical characteristics, vegetation, how depth to saturated soils varies during the course of the year under run-of-river management, amongst other factors is important to finalizing the species of native plants best suited to establish naturally or artificially at Site D. In general, what makes Restoration Site D intriguing from the standpoint of restoration is the possibility that a key impediment to the establishment of non-obligate riparian plants – relatively frequent and prolonged inundation - will likely be diminished or potentially eliminated completely in the future. As noted above, such would enhance opportunities for the establishment of a variety of non-obligate riparian plant species.

[Figure 27. Digital rendition of restoration at Site D under run-of-river management]

In contrast to Restoration Site C, the shoreline surfaces that comprise Restoration Site D appear to be less influenced by direct outflows from tributaries. Certainly, the surfaces that comprise Restoration Site D are associated with Deadman Wash greater delta ecosystem. Yet, being on the leeward side of main flow energies emanating from Deadman's Wash, the majority of Restoration Site D appears to not be frequently influenced by flood scour and, at least under past management of Horseshoe Dam, are areas where sediment aggradational processes dominate. In brief, the morphology of Restoration Site D appears to have changed little over last few decades, thus providing an opportunity to not only foster the establishment of a robust, non-obligate riparian plant community (per above), but to artificially manipulate surfaces in a manner that would enhance the diversity of native plants.

For example, establishing so-called 'vernal' pools may be an option, which are precipitation-filled seasonal pools that contain water and augment water availability during hot and dry periods. The term 'vernal pool' comes from mesic settings and refer to depressions that trap water and promote plant growth when temperatures are suitable in the spring and are followed by brief waterlogged-terrestrial stages that culminating in extreme desiccating soil conditions of extended duration (Franciska Fryjoff-Hung 2018; Keeley and Zedler 1998). Vernal pool plant communities can be floristically, topographically, and geographically autonomous, and are one of the few low-elevation habitats in California that are dominated by native plant species (Barbour et al., 2007).

Although studied in geographies and climates much different than central Arizona, the establishment of vernal pools via targeted/limited earthmoving – essentially depressions of varying sizes and shapes on surfaces that are not frequently inundated - could augment water availability to allow the establishment of flora that otherwise could not survive Arizona's hot, dry season. Length of inundation depends on the amount, timing, and duration of precipitation events throughout the season, as well as pool microtopography and landscape position, which affects both within and between year variability (Bauder 2005). One of the great ecological benefits of such depressions or pools is that they serve as ecological refuges and primary habitat for a number of endemic specialists, many of which are adapted to these ephemeral ecosystems and are able to tolerate highly variable timing for the onset and duration of the growing season and endure long periods of extreme dryness (Zedler 2003).

The great challenge of establishing such depressions at Horseshoe Reservoir (or anywhere) is that, to be effective, the pools need to be in a location where they collect runoff waters that are sediment depleted (i.e., in settings where the next surface flow does not fill pools with sediment). In this sense, the establishment of vernal pools may make sense at Restoration Site D, but not at Restoration Site C, which appear to be much more frequently and directly impacted by tributary sediment and water inflows. One of the case studies highlighted in Section Two of this report is Avocet Pond, which is located in the Merced Vernal Pools and Grassland Reserve near Merced, California. In that project, the potential for establishing vernal pools was evaluated via a 2D hydrodynamic model (Franciska Fryjoff-Hung 2018).

With low water availability as the main challenge to establishing native bottomland plant communities at Horseshoe Reservoir, such strategies may be worth considering as a way to augment water availability and thus native plant diversity. Yet, this option would only be viable

per access by heavy equipment that would allow such pools to be excavated. Regardless, the establishment of a non-obligate riparian plant community at Site D would be the principal emphasis with the establishment of vernal pools done as a minor component and, at least initially, at pilot and experimental scale.

The proposed restoration goal for Restoration Site D and the complicating factors that may pose a challenge to realizing that objective are summarized in Table 5.

Table 5. Summary of long-term restoration goal and complicating factors for Restoration Site D.

Provisional Restoration Goal	
A xeroriparian forest composed of such nonobligate riparian plants as mesquite (*Prosopis* spp.), catclaw acacia (*Acacia greggii*), desert willow (*Chilopsis linearis*), and paloverde (*Parkinsonia* spp.). Vernal pool-like depressions could provide physical conditions conducive for the establishment of other plant species, as well.	
Complicating Factors	
Low water availability	As everywhere, prolonged periods of drought will certainly impact native plant communities that ultimately establish on Restoration Site D. That noted, species such as *Prosopis, Acacia, Parkinsonia* are drought tolerant and are likely to survive drought periods. As such, drought/low water availability as a challenging factor is not as worrisome as it is for obligate riparian and wetland plant communities. In addition, the vernal pool idea of establishing a series of depressions that could augment water availability for key native bottomland plants may be worth considering.
Flood scour	Being on the leeward side of the mouth of Deadman's Wash, Restoration Site D is protected from the direct impacts of flood scour from that tributary. In addition, much of the site is several meters higher in elevation than the dynamic parts of the Verde River bottomland and, as such, are protected from flood scour when the Verde River experiences high magnitude flooding.
Soil salinity	Soil salinity levels could be elevated as a result of past inundation by impounded waters behind Horseshoe Dam. However, non-obligate riparian plants are, in general, much more salt tolerant than obligate riparian species. Soil testing and/or pilot revegetation is warranted if artificial revegetation actions are going to be considered.
Prolonged inundation	The important and central biophysical assumption for Restoration Site D is that run-of-river management will reduced the frequency that this site is inundated which, in turn, will foster conditions more suitable to the establishment of xeroriparian plant community
Competition from non-native plants	Certainly, the establishment of non-native plants could be a challenge at this site. Monitoring of biophysical conditions should be a priority with targeted management of non-native plants encouraged only if the establishment of undesirable plants occurs

	at levels that compete with native plant establishment (see discussion in Appendix A).
Proposed Next Steps	

i.   Conduct additional targeted site reconnaissance and analysis of aerial photography is warranted with focus on describing current biophysical conditions and frequency of past inundation.

ii. Establish a thoughtful, realistic monitoring program to gauge vegetation response and variation in shallow groundwater elevations after run-of-river management is implemented.

iii. Targeted pilot revegetation to gauge the realities of conducting revegetation in such a remote site as well as to understand the suitability of site physical and chemical characteristics to supporting key xeroriparian plant species. Small vernal pool-like depressions could also be established as part of a pilot program to evaluate the validity of this approach to foment water availability and increase native plant diversity.

RESTORATION SITE E
Overview
Restoration Site E encompasses surfaces that are located along the western shoreline of Horseshoe Reservoir just to the south of the mouth of Lime Creek (Figs. 9 and 28). This is a popular site for visitors to Horseshoe Reservoir with the flat, upper portions of the site being an area where visitors frequently park.

Figure 28. Aerial photograph showing the mouth of Lime Creek with potential planting sites and visitor parking area (indicated with arrows) constituting the heart of the restoration objective for Site E. The southern most arrow points directly at the shoreline inlet discussed in text below. The blue line delineates the elevation of the conservation pool (i.e., when the elevation of surface waters behind Horseshoe Dam are at 617.7 m (2,026 ft)).

There are two characteristics that make Restoration Site E attractive as a potential restoration site. First, the site offers a several different surfaces that may be conducive to the establishment of several types of bottomland plant communities. Non-obligate riparian communities may be

appropriate for higher elevation surfaces (up to and including the flat surface where visitors often park) (Fig. 29). Along the shoreline of the reservoir south of the mouth of Lime Creek, conditions may be suitable for obligate riparian plants. This may be particularly true toward the southern portion of the site where an inlet into the shoreline is located and whose lower elevation appears conducive to holding waters for extended periods of time following the retreat of the reservoir pool (Fig. 30). The extent that such would occur under run-of-river management is unknown at this point but can be better ascertained with hydrologic modelling similar to what is emphasized in Section Five. If inlet water availability does prove to be appreciably higher under run-of-river management, such may offer conditions appropriate for the establishment of obligate riparian and/or emergent native plants. Regardless, native plant establishment at this site would emphasize non-obligate riparian species on higher elevated surfaces (Fig. 31).

Figure 29. Photograph of Restoration Site E surfaces that may be conducive to the establishment of non-obligate riparian plant community in a park-like setting. Under current management, this area is frequently used by visitors to Horseshoe Reservoir as an access point for recreation.

Shoreline inlet

Figure 30. Overview photograph of Restoration Site E showing surfaces currently used for parking (note the two pickups in the photograph) as well as the shoreline inlet.

Second, given the importance of this site to visitors, Restoration Site E could serve as an 'official' public interface. One can imagine, for example, the parking area having a kiosk that provides information not only on the history and importance of Horseshoe and Bartlett Reservoirs, but also SRP's work to provide water to downstream users as well as efforts to

protect and restore native bottomland habitat. Parking spaces could be established in and amongst a mesquite bosque plant community that spreads down slope to scattered obligate riparian and possibly even wetland plants (Fig. 31). Areas relatively free of vegetation could be maintained for purposes of access to the reservoir and viewing. It is important to note that Site E is adjacent to US Forest Service Botanical Area, with the potential development of the site augmenting public access to that area as well as Horseshoe Reservoir.

[Figure 31. Digital rendering of Restoration Site E.]

Advantages and Drawbacks

There are several important unknowns that need to be considered and looked at carefully before planning towards the above objectives can go further. How run-of-river management will affect water availability at this site will need to be better understood, particularly with regard to how the decline in inundation frequency by impounded waters could potentially rule out the establishment of obligate riparian and wetland plants at this site. The extent that SRP moves forward on making this site an official visitor area will depend on a variety of internal considerations and factors.

The proposed restoration goal for Restoration Site E and the complicating factors that may pose a challenge to realizing the restoration goal is summarized in Table 6.

Table 6. Summary of long-term restoration goal and complicating factors for Restoration Site E.

Provisional Restoration Goal	
Establish pockets of multiple bottomland plant communities, including a xeroriparian forest composed of such nonobligate riparian plants as mesquite (*Prosopis* spp.), catclaw acacia (*Acacia greggii*), desert willow (*Chilopsis linearis*), and paloverde (*Parkinsonia* spp.) on upper surfaces, obligate riparian plants on lower surfaces that comprise the shoreline inlet. Developing this site for public interface is part of the goal as well.	
Complicating Factors	
Low water availability	As everywhere, prolonged periods of drought will certainly impact native plant communities that ultimately establish on Restoration Site E. That noted, species such as *Prosopis, Acacia, Parkinsonia* are drought tolerant and are likely to survive drought periods.
Flood scour	Upper surfaces (e.g., near the current parking area) as well as lower surfaces like the inlet are likely not vulnerable to flood scour from flows coming down Lime Creek and the Verde River. Upper elevated surfaces are not vulnerable due to their higher elevation. The shoreline inlet feature is tucked into the west of where the highest vector Verde River flow energies would occur (at least currently given the current position of the low-flow channel).
Soil salinity	Elevated soil salinity levels could be a concern on lower surfaces of the inlet feature, particularly if revegetation with obligate riparian plants is being contemplated. Testing of soil salinity levels in that portion of Restoration Site E would be recommended in that case. Targeted pilot revegetation would also go a long way to understanding if site conditions would be conducive to survival of obligates and other plant species as well.
Prolonged inundation	Not a concern on higher elevated surfaces (e.g., in and near the parking area) and only a concern in low lying areas where revegetation with non-obligate riparian plants is being contemplated. As with other sites, the important assumption is that run-of-river management will reduce the frequency and duration that this site is inundated which, in turn, will foster conditions more suitable to the establishment of xeroriparian plant community
Competition from non-native plants	As with other sites, the establishment of non-native plants could be a challenge at this site, particularly if the site is managed for public visitation. Monitoring of biophysical conditions is encouraged with targeted management of non-native plants encouraged if establishment of undesirable plants occur in levels that surpass what SRP deems desirable (see discussion in Appendix A).
Proposed Next Steps	
i. Conduct additional targeted site reconnaissance and analysis of aerial photograph is warranted with focus on describing current biophysical conditions and frequency of past inundation.	

ii.   Install several piezometers to monitor variation in shallow groundwater elevation. This
would be particularly important if the establishment of obligate riparian and wetland
plants is part of the restoration objective.

iii. Conduct targeted soil salinity testing along with pilot revegetation to gauge the suitability
of site physical and chemical characteristics to supporting key obligate and non-obligate
riparian plant species.

RESTORATION SITE F
Overview
Restoration Site F is a low-lying, frequently inundated area immediately to the east of Horseshoe
Dam (Fig. 9 and Fig. 32). The surfaces of Restoration Site F that are particularly intriguing from
a restoration standpoint are the relatively low in elevation with gentle slopes rising to
surrounding uplands, ranging in elevation from about 596 m (1,955 ft) to 600 m (1,968 ft) (Fig.
33). Daily pool surface elevation data for the last two decades provided by SRP indicates that the
majority of the lower elevated surfaces that comprise Restoration Site F were inundated over
96% of the time during the 2001 – 2021 period.
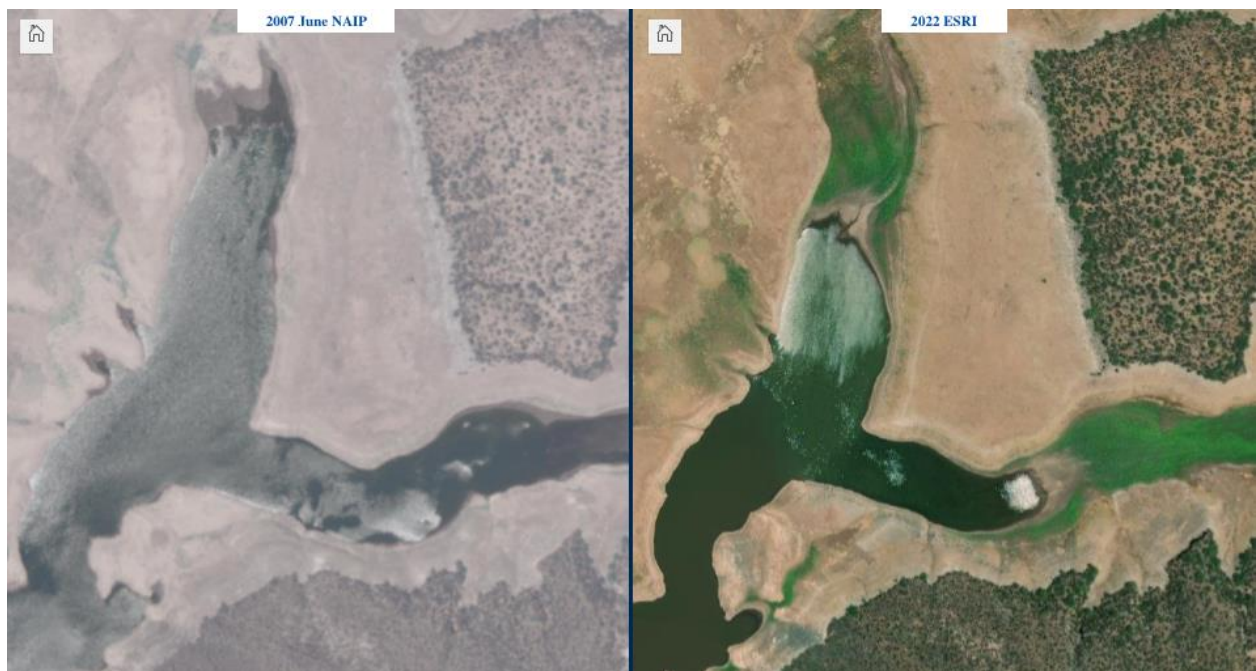
Figure 32. Aerial photograph of Restoration Site F showing low lying parts of the site retaining
water even when the surface water elevation of Horseshoe Reservoir pool was much lower than
average. In June 2007 (aerial photograph at left), water elevations were at about 594.5 m (1,950
ft). In 2022 (aerial photograph at right), water surface elevations were at 598 m (1,962 ft).
Significant parts of Restoration Site F still maintained pooled waters even during these time
periods.

The high frequency of inundation coupled with gentle topography could provide conditions well-
suited for establishing an emergent plant community, possibly intermixed with obligate riparian

and non-obligate riparian plants on surrounding higher elevated surfaces (Fig. 34). Establishing an emergent, wetland plant community hinges on dam operational flexibility that allows Horseshoe Dam gates to be closed at strategic times to maintain a small pool of water that would allow wetland, emergent plants to persist during the hot, dry months.
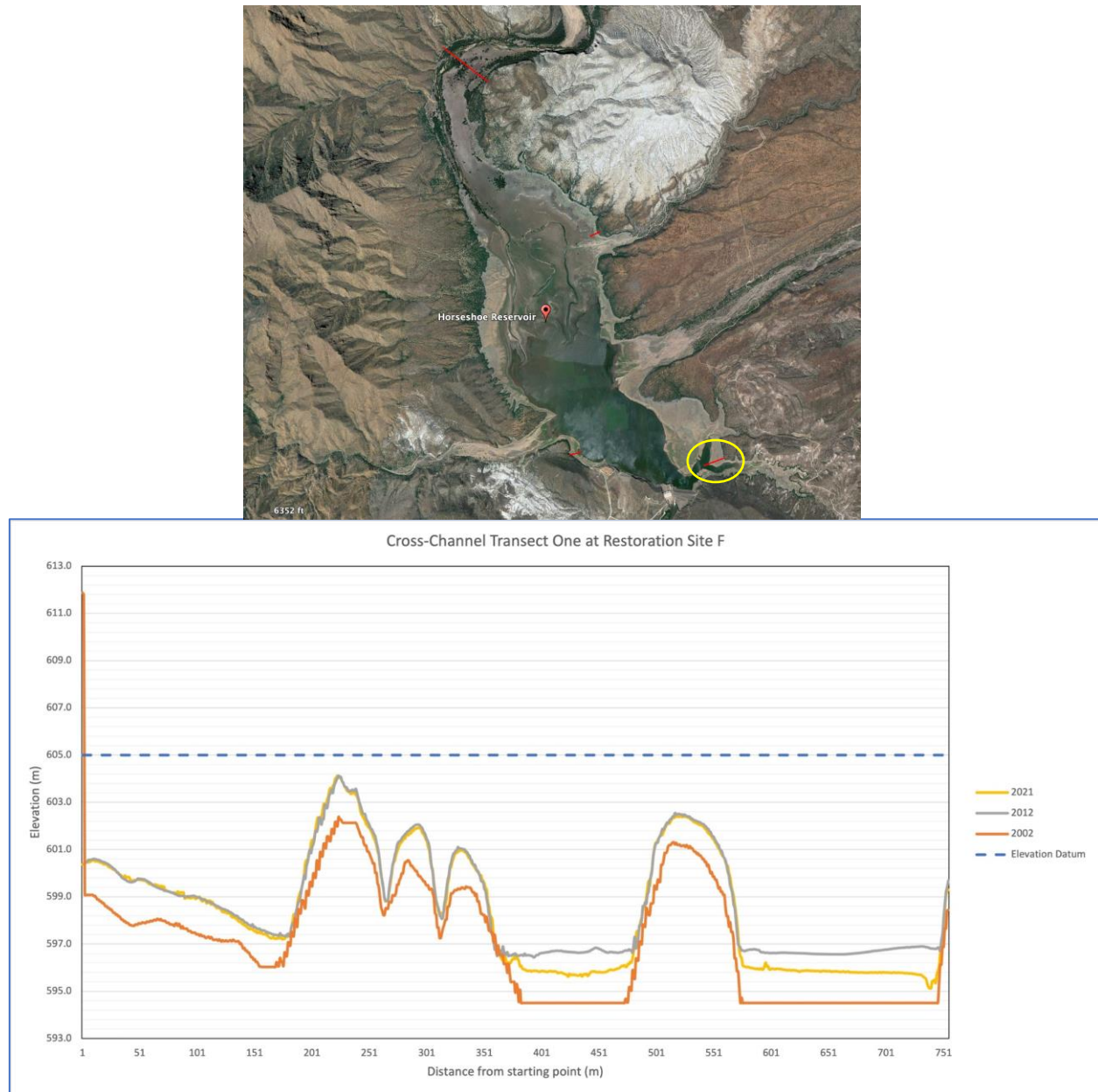
Figure 33. Cross-sectional data across Restoration Site F are gathered along the transect indicated in the yellow circle in the aerial photograph above the graph. Data from 2012 and 2021 obtained via LiDar platforms, data from 2002 are much less accurate and secured via multispectral platforms. Low elevated surfaces across the transect would be the focus of efforts to establish native emergent wetland plants if flexible management of Horseshoe Dam gates in the future would allow for persistence of pooled water during the hot, dry season.

Several important information gaps need to be addressed to better understand the validity of establishing an emergent, wetland plant community at Restoration Site F. First, additional site reconnaissance and mapping needs to be carried out to better map topography, soils, and vegetation at this site as part of developing a spatial design of where emergent, obligate riparian and non-obligate riparian plants might be established.

Figure 34. Photograph of Restoration Site F looking due west. Surfaces in the foreground extending away from the reservoir pool are steeper than those to the west (or upstream) of the pool. As such, surfaces in the foreground may be appropriate for obligate riparian and/or non-obligate riparian plants, while the surfaces in the background (as well as surfaces under water at the time the photograph was taken) may be appropriate for native emergent plants.

[Figure 35. Digital rendition of restoration at Site F.]

Second, how run-of-river management will impact surface water elevations will need to be assessed in order to determine (i) if the lower elevation surfaces that comprise Site F will actually hold water for extended periods of time during the dry, hot season, and (ii) whether such water holding potential allows maintenance of the saturated soil zone during the dry, hot season at elevations appropriate for the survival of emergent wetland and/or obligate riparian plants. There is also a flip side to above concern regarding desiccation of emergent and/or obligate riparian plants. Presumably, large flows of significant duration from the Verde River will provide for a reservoir pool behind Horseshoe Dam even with gates wide open. Such would likely not negatively impact an emergent plant community at Site F but could impact obligate riparian plants and certainly non-obligates. What might be the footprint and duration of such a pool is important to ascertaining the confidence of realizing any revegetation objective at Restoration Site F in the long-term.

Third, how run-of-river management will affect sediment evacuation from Horseshoe Reservoir may be particularly important for this site. Continuous pass through of Verde River flow, particularly during times of high Verde River flow when dam gates may be a maximum capacity, has the potential for creating a headcut that would migrate upstream through reservoir alluvium. Such is desirable from a standpoint of evacuating sediment from the reservoir and redistributing sediment along downstream reaches of the Verde River channel, yet such physical changes in reservoir morphology will need to be taken into account when understanding the validity of establishing an emergent plant community that will be dependent on saturated soil conditions during the dry, hot season. In a nutshell, morphologic change driven by an upstream migrating headcut could impact stage-inundation relations and water availability of Restoration Site F.

Putting the above unknowns aside for the moment, the potential of establishing an emergent wetland community in Horseshoe Reservoir is exciting for several reasons. Emergent wetland ecosystems have potential to improve water clarity and quality, reduce rates of shoreline erosion and sediment resuspension (James and Barko 1995), as well as provide valuable habitat for native fish, waterfowl and aquatic mammals (Dibble et al. 1996). As already discussed in the context of establishing native obligate riparian habitat, the boom/bust hydrology that is typical of the arid western U.S. makes such an aim challenging. Long periods of high water can deprive emergent plants of light and oxygen, resulting in mortality. On the other side of the spectrum, low water conditions can desiccate plants, though emergent plants as *Carex*, *Typha* and other genera of the family *Cyperaceae* exploit such biological strategies as the production of desiccation-resistant seeds and tubers to overcome low-water conditions. This means that a native emergent wetland plant community that is desiccated during a drought period has potential to reestablish naturally once rains and flow return.

The Arcadia Lake case study highlighted in Section Two focuses on establishing an emergent, wetland plant community in that lake. In addition to summarizing some of the challenges associated with water management, that case study highlights other challenges, including herbivory of desired vegetation by fish and turtles that posed a problem to establishment and long-term viability. Managing Typha sp. may also be a challenge given its aggressive establishment and growth rate that can outcompete other desirable species.

Table 7. Summary of long-term restoration goal and complicating factors for Restoration Site F.

Restoration Goal	
Establish an emergent, wetland plant community that provides habitat for native fish and waterfowl, amongst other species. Establishing obligate and non-obligate riparian plants on surrounding higher elevated surfaces would also be a central restoration at this site.	
Complicating Factors	
Low water availability	Although Restoration Site F was inundated frequently under past management, run-of-river management will likely reduce the frequency and duration that this site is inundated. Such could become a challenge to establishing emergent plants if Horseshoe Dam gates cannot be closed at opportune times before and/or during the dry period to augment water availability.
Flood scour	This site is protected from the direct impacts of flood scour though a statistically rare, high magnitude flood would likely impact the site. In addition, if headcut formation is included under the 'flood scour' banner, the upstream migration of a headcut from Horseshoe Dam would likely impact pool formation and duration at Restoration Site F, potentially to thresholds that could compromise the potential for establishing emergent and/or obligate riparian plants. .
Soil salinity	Elevated soil salinity levels could be an issue here as a result of past inundation frequencies. However, such will likely only be a concern for obligate riparian plants given higher tolerances of emergent and non-obligate plants to soil salinity.
Prolonged inundation	Given the likelihood that run-of-river management will significantly reduce the frequency and duration that Site F surfaces are inundated, the potential that parts of Site F will still be inundated for significant periods of time will likely only be an issue for parts of the site where non-obligate riparian plantings are being planned.
Competition from non-native plants	Certainly, the establishment of non-native plants could be a challenge at this site, particularly given the importance of maintaining pooled waters and saturated soils at this site (in order to provide conditions needed for emergent plants). Bermuda grass (*Cynodon dactylon*), cocklebur (*Xanthium strumarium*), buffel grass (Cenchrus ciliaris), *Sesbania herbacea*, and a host of other non-native weeds have the potential to establish and take over. On a more optimistic note, some emergent native wetland species can establish aggressively and outcompete non-native, invasive plants. For example, once established, *Typha* sp. can increase its extent and distribution rapidly (which could become an issue in its own right). Monitoring biophysical conditions should be a priority with targeted management of non-native plants encouraged if establishment of undesirable plants occurs at levels that surpass what SRP deems desirable (see also discussion in Appendix A).

Proposed Next Steps
i.   Conduct additional targeted site reconnaissance (when the site is not under water) and analysis of aerial photography is warranted with focus on mapping potential wetland/emergent, obligate riparian and non-obligate riparian planting zones.
ii.   Establish a thoughtful, realistic monitoring program to gauge vegetation response and variation in shallow groundwater elevations via the installation of piezometers.
iii.   Coordinate with native fish studies to determine potential for complementary restoration objectives.
iv.   Conduct targeted pilot revegetation efforts to gauge the potential effectiveness of establishing a variety of different wetland, obligate riparian and non-obligate riparian species at this site.

SECTION FIVE
INFORMATION GAPS AND SUGGESTED NEXT STEPS

In this section, next step actions are identified and summarized that are important toward finalizing the overall restoration program for Horseshoe Reservoir, including the finalization of the location of the restoration sites, restoration objectives, the restoration tactics that will be employed to meet objectives, as well as post-implementation maintenance and monitoring needs. The majority of the actions summarized below address important gaps in information associated with finalizing Horseshoe Reservoir restoration plans. Although the actions listed below are more or less on the same level of priority with regard to their importance, there are several whose implementation should be initiated as soon as possible, ideally before the 'official' start of subsequent phases of the overall Horseshoe Reservoir Study. Initiating monitoring of shallow groundwater and other biophysical site attributes is a good example of such. In addition, several actions summarized in this section essentially constitute deeper dives or extensions of work conducted as part of this report and are cost-effective with great potential of providing much needed information at relatively minor expense. The above is underscored in the below summarizes for actions that fall into either of these categories.

CONDUCT ADDITIONAL SITE RECONNAISANCE AND MAPPING
Conducting additional site reconnaissance that focuses on morphologic, soil, vegetation conditions of the sites being proposed for restoration is a priority. Such will provide a multitude of insights that will address key information gaps related to the selection of restoration sites, development of restoration objectives, plant lists, management priorities, restoration tactics, monitoring priorities, amongst other considerations. Conducting additional site reconnaissance during a period when Horseshoe Reservoir pool is low and the majority of the reservoir is dry is essential, particularly for restoration sites B and F. Restoration Site B is a particular priority given that it was underwater throughout the year that this study phase was conducted. We were able to visit Site F towards the end of last year. Regardless, having a small budget and windows of time to visit all sites will help immensely to evaluate targeted site features and fill in important information gaps associated with key questions that would be important to address as part of finalizing the work stream for subsequent phases of the overall Horseshoe Reservoir Restoration project.

FURTHER REVIEW OF LITERATURE AND FOLLOW-UP ON CASE STUDIES
The review of literature conducted as part of this phase of the Horseshoe Reservoir Restoration Study covered a broad swath of thematic territory that included past research concerning reservoir and lake ecology, restoration of lakes and reservoirs, ecology and hydrology of arid rivers and streams, restoration of bottomland plant communities, Verde River hydrology and ecology, Horseshoe Reservoir management, amongst others. The time spent to identify, organize and synthesize literature varied with the specific theme. As the restoration of bottomland plant communities in Horseshoe is the central theme of this study, the dive into literature concerning reservoir restoration was the deepest of all the themes that were pursued. Regardless, it is safe to say that additional helpful literature exists that was not identified nor summarized in this report given time constraints. All to note that SRP may desire a deeper dive into additional literature on specific topics of interest.

Similar to the potential need to conduct additional review of pertinent literature, following up on certain aspects of one or more of the case studies presented in Section Two of this report may also be important. Two of the case studies – Roosevelt Lake and Elephant Butte Reservoir – are neighboring reservoirs that were visited jointly by the authors of this report and SRP personnel. Field visits to selected additional sites could also be valuable. For example, visiting the mitigation sites at the Lake Isabella dam reconstruction project stands out as a potential priority that may offer valuable insights concerning vegetation restoration tactics at the inlet end of a reservoir. If budget and time constraints do not permit visiting case studies in distant geographies (at least more distant than Elephant Butte Reservoir and Roosevelt Lake), identifying and following up with project personnel via phone calls, emails to discuss targeted questions associated with the case studies would likely yield great dividends without much cost.

MODELING POOL SURFACE WATER ELEVATIONS BEHIND HORSESHOE DAM
In the context of identifying potential sites for habitat restoration in Horseshoe Reservoir, one of the key unknowns is the extent to which run-of-river management will impact the reservoir's limnological characteristics, particularly with regard to variation in the surface elevation of the reservoir pool. It is safe to assume that one of the more significant impacts of managing Horseshoe Dam with gates wide open the majority of the time will be a reduction in the frequency and duration that impounded surface water levels behind Horseshoe dam occur at elevations near conservation pool status. Key questions pertinent to bringing back native bottomland vegetation in Horseshoe Reservoir that such hydrologic modelling can potentially address are:
- What will pool surface water elevations look like during the course of an above-average, average, and below-average precipitation year with gates wide open? Another way to put this question is, what would the graph of Horseshoe Reservoir pool surface water elevations (Fig. 11) look like given: (i) the same flow inputs from Verde River during that two-decade period of time, but (ii) with Horseshoe Dam gates wide open?
- How quickly can large pools of impounded water (with surface water elevations near conservation pool status) be evacuated downstream with varying Verde River discharges into the reservoir? This gets at key threshold questions related to water inundation for desired species at specific restoration sites. In other words, taking the last two decades as a reflection of what precipitation and Verde River streamflow conditions will be like during the next two decades, what will be the frequency and duration that desired bottomland vegetation will be under water (particularly vegetation planted at low elevations (e.g., near the central portion of the reservoir) with run-of-river management in effect?
- At the other end of the hydrologic/water availability spectrum, to what extent would gates need to remain closed to allow a pool of water behind the dam of sufficient footprint/elevation to form that would inundate key parts of the reservoir shoreline during May and June (e.g., key parts of the shoreline of Restoration Site F that would allow emergent, wetland plants to get through the hot, dry period)? Assuming for the moment such inherent flexibility in the management of Horseshoe Dam is realistic, is it technically possible to form such a pool during a period of drought when Verde River flow into Horseshoe Dam would be a trickle? Modelling the above would not only provide insights into the feasibility of establishing wetland emergent plants but also the duration that Horseshoe Dam gates may need to be closed (to allow a pool of worthwhile

elevation to form, if even feasible) and whether such would be in the realm of realistic from a management standpoint.

ESTABLISH MONITORING PROTOCOLS

Establishing monitoring protocols that will provide detailed quantifiable data will allow SRP to gauge the impacts that run-of-river management and/or on-the-ground restoration actions will have on bottomland plant communities, channel morphology, shallow groundwater, amongst other variables. Even if on-the-ground restoration actions are not ultimately conducted (or limited), the effects of changing dam management from one that emphasizes water storage to run-of-river is worthy of monitoring in its own right. Protocols for monitoring these and other factors are well documented (see review by Bunting et al. 2020b). In addition, so-called long-term monitoring sentinel sites are being established as part of a global network to provide insights in natural resource change at site to landscape scales (see Briggs et al. 2022b). In general, combining monitoring data gathered from remote platforms (e.g., drones to satellites) with targeted on-the-ground monitoring stations is ideal, allowing narrow/detailed to broad/less detailed quantification of change.

Monitoring should be initiated as soon as possible to capture site biophysical characteristics prior to changing dam management and/or prior to initiating bottomland restoration efforts (including management of non-native species if such is deemed worthwhile). Have two years of data prior to initiating management change and/or restoration actions is better than one. Horseshoe Reservoir sites where biophysical changes are most anticipated are sound candidates for establishing monitoring. As a first step that potentially could be completed prior to the initiation of subsequent phases of the overall Horseshoe Reservoir Study, a priority list of monitoring questions (defining needs), types and location of monitoring, methods, data organization, storage and analysis could be developed. A concise and clear document that summarizes a monitoring program for Horseshoe Reservoir. Having a such a document prepared and agreed to would provide the foundation to effectively launch monitoring in a timely manner when resources become available.

INSTALL PIEZOMETERS TO QUANTIFY DEPTH TO SHALLOW GROUNDWATER

A critical piece of information for identifying suitable sites for obligate riparian and wetland plants in the Horseshoe Reservoir study area is variation in shallow groundwater elevations, particularly with an eye towards understanding how far shallow groundwater elevations fall during the hot, dry months prior to the onset of monsoonal precipitation. Installing piezometers (and/or taking advantage of existing wells) to monitor ground water conditions is an effective way to monitoring groundwater elevations and flow. A piezometer is a tube that is placed in the soil to depths below the water table and extends to the soil surface and is open to the atmosphere to allow easy access for measuring depth to water table. In some cases, the piezometer is made of polyvinyl chloride (PVC) or chlorinated polyvinyl chloride (CPVC) and is housed inside a metal casing that protects the piezometer and allows the entire unit to be driven into the ground. Installing perforated PVC or CPVC pipes can be done inexpensively. Lightweight and inexpensive "minipiezometers" also can be used to conduct numerous measurements in remote locations (Baxter and Hauer 2003). The number and locations of monitoring points required to give a realistic picture of ground water depth and fluctuation depend on several factors, including

the size, topography, geology, and soil characteristics of the site. Small sites characterized by relatively homogeneous hydrogeologic conditions will require fewer monitoring points than larger, more complex sites (Freeze and Cherry 1979; Todd 1980; many others).

Installing wells along a transect perpendicular to the stream channel will provide information on how ground water levels change with distance from the main channel as well as whether the stream reach that you are working on is a gaining or losing reach with respect to streamflow. Such information can be extremely valuable for designing planting strategies. Research has been conducted on species-specific ground-water depth thresholds along ground water gradients extending away from the main channel (Springer et al., 1999; Stromberg et al. 2009; others). Such research, combined with knowledge of site variation in shallow groundwater elevation allows practitioners to know when and where to substitute obligate phreatophytes with facultative phreatophytes or more xeric species.

Based on current understanding of hydrologic conditions of Horseshoe Reservoir, two transects of piezometers appear particularly important to evaluating the validity of several of the proposed restoration sites and toward finalizing revegetation design (particularly the types of species and location): (i) one piezometer transect consisting of five or more piezometers along transect two, which intersects Restoration Sites B and C; and (ii) another transect of piezometers along targeted parts of Restoration Site F.

CONDUCT TARGETED PILOT REVEGETATION EFFORTS
There are a two central benefits to conducting pilot (small scale) revegetation efforts in targeted parts of the Horseshoe Reservoir study area where establishing native bottomland plants via artificial revegetation actions is strongly being considered. First, no matter how exhaustive future hydrologic modeling and biophysical investigations are, it is likely that important information gaps will persist with regard to the types of native bottomland plant communities that can be established in various parts of the Horseshoe Reservoir ecosystem. Conducting pilot revegetation efforts in key areas and monitoring survival and growth of the species that are planted can provide critical and directly applicable data and information to benefit the effectiveness of larger scale revegetation efforts beyond what biophysical investigations can provide on their own.

Second, pilot revegetation efforts can and should be implemented cheaply and at small scale. For example, planting pilot revegetation patches at Restoration Site B could be carried out in phases and in a manner where each phase not only builds on one another but involves limited plantings (a few thousand willow poles) that can be accomplished cheaply. Monitoring (see below) should be carried out as an inherent part of pilot revegetation such that collected monitoring data inform subsequent phases of revegetation, particularly with regard to the selection of sites and species most conducive to long-term viability.

Third, although much smaller in scale, the process of carrying out a pilot revegetation project is exactly the same as the process for carrying out a full-scale project. Finalizing project objectives, securing project budget, evaluating site biophysical conditions, finalizing plant lists, finalizing and carrying out revegetation protocols, and conducting monitoring and maintenance actions are all essential elements of the overall design of full-scale revegetation efforts just as they are for

pilot projects. In this regard, the process of designing and implementing a pilot effort is exactly the same as that of a full-scale project. The big difference is spatial scale. The smaller footprint of pilot projects equates to much reduced material, equipment, and personnel needs that, in turn, equates to much reduced time and budget requirements. In this sense, pilot projects can be viewed as a process dress rehearsal for implementing a much larger scale project; a dress rehearsal that will provide insights to not only key biophysical questions (e.g., can willows be established and persist at a specific site?) but a variety of non-biophysical and process questions that will allow SRP to assess on-the-ground project implementation realities (e.g., can patches of revegetation as described for Restoration Site B actually be established given realities of budget, personnel and equipment availability, varying site conditions, etc.?).

MEASURE SOIL SALINITY

As noted in Section Three, elevated soil salinity levels can have a significant bearing on the types of plants that may be suitable for a wildland revegetation effort. It may be valuable to measure soil salinity levels at several of the proposed restoration sites, particularly ones where obligate riparian plants are being considered, which as a group have low salt tolerances. In situ measurement with soil salinity sensors is commonplace and quite accurate when compared to measurements by conventional analytical methods (saturation-paste-extract and soil water suspension) (Hussain and Al-Hawas 2008). There are also approaches to map soil salinity using remote sensing data (Eldiery et al. 2005). On-going restoration efforts along the Middle Rio Grande use a Geonics EM-38 meter to measure electromagnetic induction (EMI) in order to map patterns of soil electrical conductivity (ECa). In this approach, bulk ECa is measured at two soil depths with results producing an accurate site map of soil salinity levels that, in turn, will inform bottomland revegetation (Briggs et al. 2022a).

Regardless of the method used to measure soil salinity, it will be important to develop criteria to prioritize where measurement of soil salinity will offer important data and information in determining the feasibility of realizing restoration objectives. In this regard, priority sites are those: (i) where reestablishing obligate riparian plants is part of the restoration objective; (ii) where obligate riparian plants are currently not established in great numbers; (iii) that do not frequently experience streamflow (either from the Verde River or tributaries); and (iv) that were inundated frequently under impounded waters.

GATHER ADDITIONAL INFORMATION AND DEVELOP CRITERIA FOR MANAGING NON-NATIVE PLANTS

As noted on several occasions in Section Four, management of non-native plants will be an issue at almost all restoration sites. Methods on how undesirable plants will be managed need to be finalized. Although finalizing how undesirable plants will be managed or treated is vital, it is important to note that such information is readily available for most species. In this regard, the key is to summarize management options for targeted plants that will allow SRP to select methods that are most appropriate and effective. Appendix A summarizes methods for managing four key non-native plants, but there are likely other plants that SRP may decide to manage in addition to those highlighted in Appendix A, including cocklebur (*Xanthium strumarium*), kochia (*Kochia scoparia*), and bermuda grass (*Cynodon dactylon*). All to underscore that it may be important to expand the review of literature and experiences on managing undesirable plants,

particularly as additional data and information are collected on response of the bottomland plant community to changes in flow management.

With the above noted, what is ultimately more critical is to develop criteria that will guide SRP on the what, when, and where of managing non-native plants. In general terms, the management goal will be to maintain the extent and distribution of targeted non-native plants at reasonable levels. What is deemed 'reasonable' will need to be defined and quantified in a manner that allows SRP to gauge management effectiveness. Monitoring programs that provide data on percent cover, abundance, and other parameters is important in this regard. But, 'reasonable' will vary with species and location. The goal for most invasive species will likely be to maintain their extent and distribution at levels such that they don't become the dominant species. However, there may be species that are currently not present in the Horseshoe Reservoir system (or at least not present in significant amounts) where SRP may want to develop a more nip in the bud approach. You see it, you eliminate it. In addition, what is deemed reasonable with regard to the extent and distribution of a particular non-native species may vary spatially even within the narrow geography of Horseshoe Reservoir. There may be species that SRP will want to keep a close eye on throughout the entire Horseshoe Reservoir system; others just in the narrow confines of a restoration site. Furthermore, what is deemed reasonable may vary from one restoration site to the next. All the above will be covered as part of finalizing criteria for managing non-native plants. Such is not difficult to do and is key to understanding and meeting long-term restoration objectives.

QUANTIFY FUTURE CHANGES IN AVERAGE VERDE RIVER FLOW

As emphasized earlier, a central challenge to the establishment and long-term persistence of obligate riparian plants and emergent, wetland plants is low water availability caused by extended periods of drought. The dry, hot months of May and June will be particularly challenging for wetland and obligate riparian plants, underscoring the importance of planting such species in areas where saturated soil elevations will not fall below the shallow root zones of these desirable species. In a bottomland setting like Horseshoe Reservoir, whether or not the saturated soil zone falls below the root zone of these plants depends largely on Verde River flow, particularly what the river offers during those critical two months.

Two central long-term concerns in this regard are impacts of climate change and upstream human development and water use. Understanding how Verde River streamflow may be impacted in the future by climate change, increased upstream water use, amongst other factors is likely in SRP's wheelhouse, particularly with regard to meeting its mission to provide adequate water to downstream users. In the context of this report, an additional water 'user' are the native bottomland plant communities of not only the Verde River, in general, but those that become established in Horseshoe Reservoir as a result of run-of-river management complemented by on-the-ground restoration actions. How will future changes in Verde River streamflow impact native bottomland ecosystems? More specific to the Horseshoe Reservoir study, how will changes in Verde River flow impact restoration objectives and tactics that are being proposed at the various sites? Will the impacts of climate change compounded by changes in upstream water use affect Verde River flow to such an extent to make the establishment and long-term viability of water loving obligate riparian and wetland plants unrealistic? Will critical hydroecologic thresholds be

crossed in the near future (in the next ten to twenty years) that will make the restoration proposals summarized in this report unrealistic?

Documentation on the effects of climate change and other impacts on streamflow is growing as well as the importance of considering the impacts of climate-induced changes on streamflow on the viability of long-term bottomland restoration objectives. For example, LeRoy et al. (2020) offers a thorough review of literature in this regard as well as practical methods for developing climate-adapted plant pallets for restoration. Regardless, understanding climate change and its impacts on hydrology is the hallmark of adaptation and effective long-term natural resource planning and management (LeRoy et al. 2020). If it appears likely that near-term changes (change over the next two plus decades) in Verde River flow will not impact important key hydroecological thresholds, then full speed ahead with establishing obligate riparian plants in one or more of the sites presented in the previous section. On the other hand, if it appears likely that key hydroecological thresholds will be crossed, SRP should look to emphasizing the establishment of non-obligate riparian plant communities.

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APPENDIX A
MANAGEMENT STRATEGIES FOR CONTROLLING SELECTED NON-NATIVE PLANTS

As part of establishing native riparian habitat at Horseshoe Reservoir, it is likely that SRP will need to control or manage non-native plants at some level. As SRP moves forward with future phases of restoring native riparian and fish habitat at Horseshoe Reservoir, the central debate should focus on not so much whether exotic, invasive species will spread, but the level of harm they do or can impose on native habitat if left unchecked, as well as what realistically can be done about it. In many situations in the southwestern U.S. and northern Mexico, non-native riparian plants outcompete native species because they are adapted to stream hydrologic characteristics that have been altered by river impoundment, water diversion, and other human interferences. In such situations, simply removing non-native plants will not necessarily promote re-establishment of native species, which may no longer be adapted to the current physical and chemical conditions of the river and its adjoining floodplain (Briggs 1996; Brown and Amacher 1999; Nagler et al. 2005; Nagler and Glenn 2013a).

For this reason, restoration projects that aim to reduce the extent and distribution of invasive, non-native riparian plants need to consider restoration tactics that go beyond eradicating these species. For example, combining targeted eradication with an environmental flow program that re-establishes critical parts of the natural hydrograph (e.g., through a spring pulse flow to promote natural recruitment of native species) may produce more effective results (González et al. 2018). In a way, SRP will be doing such if run-of-river management becomes the norm at Horseshoe Reservoir. In such a future management scenario, natural flow processes will hold greater sway they currently do, potentially providing a multitude of benefits for the establishment and viability of native species. That noted, SRP's management of non-native plants could be more selective, focusing on targeted non-native management actions that foster the establishment and long-term viability of native species. For example, managing non-native species in specific areas or sites where native plants have been artificially planted to give vulnerable native seedlings a greater opportunity to establish and thrive.

A summary of the importance for developing criteria for managing selected invasive species is provided immediately below that is followed by summaries for managing four selected invasive species that are either already present in the Horseshoe Reservoir system, or likely to be in the near future.

DEVELOPING CRITERIA FOR MANAGING NON-NATIVE PLANTS
Before embarking on a concerted effort to manage non-native riparian plants in Horseshoe Reservoir program, it will be worthwhile for SRP to have the "Is it appropriate and worth the effort?" debate. Summarized below are important questions that SRP should consider as part of this deliberation. If the majority of answers to the questions is yes, then a concerted effort to control an invasive riparian plant may be sensible. If most answers are no, it may be wise to alter the restoration program to include other objectives (Bunting et al. 2020a).

Question One: Are objectives concerning invasive species management part of a broader restoration response that includes other complementary objectives? In general, stream restoration efforts should go beyond objectives that are solely focused on reducing the extent and distribution of an invasive species and consider the broader purpose of why managing invasive species might be a priority in the first place. Is management of a particular invasive species important for improving wildlife habitat, recreation experience, channel morphologic conditions, biodiversity, the well-being of riverside communities, or other? If so, invasive species management may be a viable response as it becomes a means to an end (one tool in the restoration tool box) and not the end goal itself. What we want to avoid is a myopic focus on managing invasive species simply because the species is present. Practitioners need to be able to elucidate what the greater purpose of invasive species control is (per Clark et al. 2019). Given the multiple objectives for bringing back native riparian habitat at Horseshoe, SRP's answer to this question is certainly 'yes.'

Question Two: Are eradication objectives realistic, given funding levels, personnel, resources, the time frame, and other potential constraints? The underlying point to this question is to avoid the scattered approach of undertaking unfocused eradication until the budget is exhausted. Know the detailed labor, material, supply, and transport costs for managing invasive species and quantify exactly how much your exotic management program can realistically accomplish with available resources. Given that this report marks the end of the first phase of what is likely to be a multiple phase effort to establish native riparian and fish habitat at Horseshoe Reservoir, the answer to this question is 'to be determined' and based on the selection of restoration sites, restoration objectives for those sites, restoration tactics, and long-term management aims.

Question Three: Is the objective for managing a particular non-native species sustainable in the long term? A thoughtful answer to this important question requires understanding of the following:

- The long-term invasive plant management objective: The amount of resources needed to maintain the extent and distribution of an invasive plant at desirable levels following initial interventions can vary dramatically with target species, how rapidly the target species re-invades following initial management, site conditions, the cost of eradication tactics, among other factors. Ultimately, accurate quantification of long-term costs will be determined with experience, which can be gain by initially implementing several small-scale pilot projects. At Horseshoe Reservoir, it is advisable that the extent and distribution of non-native species is tolerated at low, desirable levels (versus complete eradication). Such an approach will make the realization of the long-term objective more realistic.
- The likely response or recolonization potential of the targeted plant following initial treatment: Does the plant re-establish quickly and strongly following initial treatment, or is regrowth following initial treatment spotty and slow? This is a critical issue for non-native, invasive riparian plant management programs that are being implemented without addressing the underlying reasons why the stream environment has deteriorated. With run-of-river management becoming the norm at Horseshoe Reservoir, it is more likely that natural flow processes will foment natural establishment of both native and non-native species. Thoughtful and regular monitoring of site conditions will provide the

information SRP will need to gauge non-native bottomland plant recolonization under this novel management approach.

- The long-term maintenance budget: It is likely that the target invasive species will re-establish at some level following initial treatment, potentially requiring follow-up management actions to maintain re-establishment at a desirable level. The cost of follow-up management will vary with the specific species being controlled, stream conditions following initial treatment, the region, access, and a variety of other factors. SRP will gain insight into long-term maintenance costs with experience. The more that SRP can secure dedicated long-term resources for managing undeseriable non-native plants, the more likely long-term habitat restoration objectives at Horseshoe Reservoir will be realized. The main scenario to avoid in this context is a one-and-done scenario where the resources available for managing invasive species only cover costs associated with initial treatment. Maintaining non-native species at desirable levels is a long-term endeavor that requires dedicated long-term resources.

Question Four: Are methods for managing and treating the invasive plants effective and appropriate? The more effective a given method is to control a target invasive species, the more likely that practitioners will be able to maintain the species at desired levels in the long term. However, on the heels of the effectiveness question is whether the control methods will do more harm than good. This is particularly an issue when herbicide is used as the main method of control. Despite EPA-approved products and labeling, it is valid to question the value of introducing potentially significant quantities of herbicide into a riverine environment. A key question for SRP in this regard is whether non-native riparian plant management objectives can be accomplished by staying within recommended volumes of active ingredient per area or by using other, non-chemical approaches. Given the track record, documentation, and experiences of managing the non-native plants selected, below, it is likely that SRP will be able to select an effective long-term management approach.

Question Five: Will the management methods that are being proposed complement biocontrol agents that may have been purposefully introduced to battle the target invasive species? Biocontrol agents have been introduced in several parts of the western U.S. to control invasive riparian species. In the Verde River watershed, the tamarisk leaf beetle (*Diorhabda* spp.) to control tamarisk is an example. If effective on reducing the extent and distribution of Tamarisk in and near Horseshoe Reservoir, the saltcedar leaf beetle may reduce the need to implement other control methods (such as treatment with herbicide or mechanical means). Effective monitoring of the beetle population along the Verde River, as well as monitoring of how tamarisk, in particular, and the overall riparian community, in general, responds has to be a priority.

STRATEGIES FOR MANAGING FOUR SELECTED NON-NATIVE BOTTOMLAND PLANTS

The Friends of the Verde River[11], which has been working in the Verde River watershed for over a decade to establish a healthy, flowing Verde River system, focuses much management attention on four non-native plants that have proven particularly invasive and troublesome: *Ailanthus altissima* (Tree of Heaven), *Arundo donax* (giant cane), *Elaeagnus angustifolia* (Russian Olive), *Tamarix ramosissima* (saltcedar). Given their experience in managing non-native plants along the Verde River, Friends of Verde River personnel should be consulted as part of finalizing management strategies as well as implementing the management strategies that are ultimately agreed on. An overview of the four problematic species and options for managing them is provided below.

GIANT CANE (*Arundo donax*)

Giant cane (*Arundo donax*) is a native of eastern Asia (Polunin and Huxley 1987) but it has been cultivated and has spread widely in many parts of southern Europe, northern Africa, and the Middle East for thousands of years (Perdue 1958; Zohary 1962; Zahary and Willis 1992). A thorough review of giant cane physiology, genetic variation, physical structure, biomass and density, growth rate and reproduction and spread is provided by Giessow et al. (2011). Bunting et al. (2020a) and Briggs et al. (2021) review management concerns associated with dense stands of Arundo as well as control methods. Giant cane was introduced in areas of the western U.S. and northern Mexico to control erosion along agriculture drainage canals and was also used as thatching for roofs. It was intentionally introduced to the Los Angeles area of California in the 1820s for roofing material and as erosion control (Bell 1997) and is now a nuisance within coastal streams and agricultural canals from central to southern California (Goolsby and Moran 2009). In the United States and northern Mexico, giant cane has become most problematic along the lower Rio Grande, where monocultures of giant cane line the river bank for several hundreds of river miles. Giant cane occupies an estimated 28,000 to 40,000 ha (70,000 to100,000 acres) in the Rio Grande Basin (Goolsby 2017), much of which straddles the international border along the Rio Grande/Rio Bravo. Encroachment into the Río Nadadores in Cuatro Cienegas, Mexico, was so rampant that it caused the extinction of endemic fish species after the river stopped flowing (Goolsby 2017). Giant cane is also invasive in Australia where it is found in every state, including the Northern Territory (Commonwealth of Australia 2018).

The rapid increase in the extent and distribution of giant cane is believed to be due to a variety of factors, including altered river hydrology that favors the spread of this species over native riparian species. The plant's high tolerance for and adaptation to fire allows it to quickly resprout after wildfire, often crowding out native species and resulting in a giant cane monoculture (Bell 1997). Giant cane is not known to provide a food source or nesting habitat for native animals (Bell 1997); however, it competes with native species such as willows (*Salix* spp.) and cottonwoods (*Populus* spp.), which provide high quality habitat to many species of wildlife, including nesting habitat for such federally endangered birds as the least Bell's vireo (*Vireo bellii pusillus*) and southwest willow flycatcher (Franzreb 1989). In addition, giant cane uses phenomenal amounts of both shallow and deep water (Moore at al. 2016)—as much as 2.4 m (8 ft) per year—to support its incredible growth rate. When its roots are in contact with saturated

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[11] Friends of the Verde River is a non-for-profit that works collaboratively in the Verde River watershed for a healthy, flowing Verde River system.

soils during growing season, its rate of growth can be as much as 5 cm per day (about 2 inches), producing more than 20 tons per ha (about 50 tons per acre) of aboveground dry mass (Perdue 1958; Iverson 1998).

In the southwestern U.S. and northern Mexico, the plant's large plume-like flower cluster (panicle) seldom, if ever, produces fertile seeds. Instead, Arundo predominately spreads vegetatively from fragmented stem nodes and rhizomes, allowing it to proliferate along disturbed waterways (Bell 1997). In addition to negatively impacting biodiversity, other impacts from giant cane invasion include altered channel morphology (it is a perfect sediment filter that can promote significant sediment deposition during high flow events, reduced visibility, loss of access and recreation sites, and other impacts). These collective impacts have provided the impetus for several giant cane eradication and control programs.

While management of established giant cane is challenging, several methods (mechanical, prescribed fire, and chemical) are promising. The overall aim of mechanical cutting and prescribed burning of giant cane is simply to reduce aboveground biomass in a manner that allows more effective subsequent application of herbicide. Mechanical cutting can be carried by using chainsaws or steel blade brush cutters. If access by heavy equipment is possible, mowing or bulldozing may be used. Prescribed burning is conducted during times of year of appropriate weather conditions (dry and warm, with not too much prevailing wind). Prescribed burns can be initiated in a variety of ways, including using fuses or torches. Depending on extent, distribution and density of giant cane, as well as weather conditions, once fire has been initiated, numerous hectares of giant cane can be burned in minutes (Fig. 36).

Figure 36. A prescribed burn of giant reed (*Arundo donax*) along the Rio Grande/Bravo in 2018. (Photo by Tamir Kalifa (New York Times).

One of the great advantages of burning – over mechanical cutting – is that practitioners will not have to deal with potentially vast volumes of cut foliage. Both mechanical cutting and prescribed burns typically do not kill giant cane and, actually, can promote significant and rapid re-growth. A month to six weeks after cutting or burning, giant cane will be waist high, but in reduced densities that provide improved access for targeted treatment with herbicide. Not only is herbicide treatment following mechanical cutting or burning more effective, the reduced biomass means less herbicide will be required overall. Foliar applications (i.e., direct herbicide application to leaves) have shown greater success (almost 100 percent) than cut-stem treatments (5 to 50 percent) (Bell 1997). Successful management along the Rio Grande/Rio Bravo has used a combination of prescribed burning with imazapyr application about a month after the prescribed burn is completed, followed by repeat treatment of re-sprouts one year later (Briggs et al. 2021).

In addition to mechanical, prescribed burning and herbicide treatment, biocontrol is also being tested. Three biocontrol species have been approved and released in the United States: 1) the Arundo wasp (*Tetramesa romana*), released in April 2009; 2) the Arundo scale (*Rhizaspidiotus donacis*), released in December 2010; and 3) the Arundo leafminer (*Lasioptera donacis*), released in December 2016. The Arundo fly (*Cryptonevra* spp.) is currently being tested in Europe. Preliminary impacts of the release of the Arundo wasp appear to show a reduction of giant cane biomass by 22 percent along 558 miles of the Rio Grande over a five-year period (Goolsby et al. 2015). Some preliminary research also appears to show water savings, socioeconomic benefits ($4 to $8 benefit per $1 biocontrol cost), and recovery of native plants as a result of the biocontrol program (Goolsby 2017). It needs to be stressed that the results of biocontrol are preliminary, with many outstanding questions remaining to be addressed. In general, the three biocontrol species may offer a good complement to ongoing mechanical, prescribed burning and chemical management of giant cane, particularly with respect to maintaining the extent and distribution of giant cane at desirable levels following an initial management phase using non-biological control strategies.

At this point, giant cane does not appear to be a dominant invasive plant species in the Horseshoe Reservoir study area. This is good news, but SRP should maintain strong vigilance given how rapidly giant cane can establish and expand its extent and distribution. Along the Rio Grande/Bravo downstream of its confluence with the Rio Conchos, the extent and distribution of giant cane went from being present in non-dominate patches to forming monoculture stands along several reaches in less two decades (Briggs et al. 2021) (Fig. 37). Once it has established in such densities, the plant is challenging and costly to eradicate. As such, SRP should endeavor to map the extent and distribution of giant cane (as well as other targeted invasive bottomland plant species) every year. If giant cane is detected, our recommendation is a 'nip in the bud' approach that supports a rapid management response that treats establishing Arundo patches with Habitat or other aquatically approved herbicide (with a proven track record of effectiveness in controlling giant cane) as soon as possible following detection.

Figure 37. Photograph of a dense stand of giant cane along the international reach of the Rio Grande/Rio Bravo prior to the implementation of management actions. In Mexico, such stands are commonly referred to as milpas (wild corn fields) given their tendency to form dense monoculture stands (photograph by Tamir Kalifa, New York Times).

RUSSIAN OLIVE (*Elaeagnus angustifolia*)
Introduction
There are a variety of in-depth sources of information on managing Russian olive, many of which are cited below. To highlight one reference, Bunting et al. (2020a) provides a concise and informative summary on Russian olive that includes case studies.

Background
Russian olive was introduced to North America in the early 1900s as an ornamental plant and windbreak. It is a Eurasian tree that has become widely naturalized within riparian areas throughout the United States. Russian olive is found in all but 13 U.S. states, is naturalized in 17, and due to its relatively wide ecological amplitude, has been reported as the fifth-most dominant woody species in western riparian areas (Friedman et al 2005). Russian olive appears to have greater impacts on upper watersheds at higher latitudes and elevations compared to tamarisk, which is more problematic along lower portions of watersheds. Within the Colorado River Basin (U.S.), for example, it has been estimated that Russian olive occupies over 16,000 ha (40,000 acres) primarily in the Upper Basin states, while tamarisk covers over 250,000 acres across the Upper and Lower Basin states (Tamarisk Coalition 2009). Russian olive is present in Mexico and

Australia, but with far fewer occurrences and is not a target for invasive control. Several publications describe the biological traits and invasion ecology of Russian olive, most of which focus on impacts in the western U.S. (e.g., Christensen 1963; Carman and Brotherson 1982; Bertrand and LaLonde 1985; Shafroth et al. 1994; Lesica and Miles 2001; Katz and Shafroth 2003; DeCant 2008); others discuss management options and treatment success (e.g., Brock 1998; Caplan 2002; McDaniel et al. 2002; Stannard et al. 2002).

A primary concern expressed by managers with regard to Russian olive is that it forms dense thickets beneath the canopy of native cottonwood gallery forests (Shafroth et al. 1995), where it becomes a hazardous fuel source and fire risk to fire-intolerant native riparian trees and shrubs. Russian olive is considered to be an invasive species in many places in the United States because it thrives on poor soil, has low seedling mortality rates, matures in a few years, propagates vegetatively (by root crown buds and root suckers), and outcompetes wild native vegetation (Tamarisk Coalition 2009). That stated, managers are also reluctant to completely remove Russian olive, owing to its abundant, edible fleshy fruits (the plant is also known as "silver berry"), which are considered a valuable food source for wildlife. It is particularly important in areas where this invasive species is one of the few fruit-bearing riparian tree-shrubs present (Edwards et al. 2014, Zouhar 2005).

Despite its fruiting capabilities, research indicates that bird species richness and density is lower in Russian olive stands compared to native-dominated riparian communities (Knopf and Olson 1984; Brown 1990). For example, with few exceptions, when it is in the understory of native-dominated cottonwood stands along the Gila River, birds prefer to nest in the native riparian trees (Stoleson and Finch 2001). Furthermore, the populations of roughly a third of the native bird species that depend on cottonwoods for cavity nesting and insect prey would be negatively impacted if mixed cottonwood-Russian olive stands were to convert to monotypic Russian olive (F.L. Knopf, personal communication [cited in Shafroth et al. 1994]). Most floodplain rehabilitation projects in the Middle Rio Grande therefore focus on at least partial removal of Russian olive to reduce fire hazard, followed by aggressive revegetation using native fruit-bearing riparian shrubs.

Control Strategies
The most common control method for Russian olive is chemical. Many practitioners have tested several herbicide applications with varying levels of success (see Case Study below). Research is currently being conducted to identify biological control agents for Russian olive, but none have been approved at this time (USDA 2014). Grazing by mature, trained goats on seedlings and younger trees is a promising component for successful control (USDA 2014). Russian olive is also susceptible to Verticillium wilt and Phomopsis canker; both are disease-causing fungi that cause gradual dieback (Worf and Stewart 1999).

An evaluation of mechanical and chemical treatments for controlling Russian olive on floodplain surfaces along the Middle Rio Grande floodplain found that although mechanical treatments can quickly reduce standing biomass, Russian olives root-sprout vigorously from buried lateral roots following physical disturbance (including fire), making herbicide treatment more effective in preventing rapid re-establishment (Caplan 2020). Details on the control methods used in their

study are likely to be useful to SRP if Russian olive becomes more of an issue at Horseshoe Reservoir or with other lands that SRP manages.

In their evaluation, Caplan (2020) used masticating tractors (150-HP front-end loaders with flail mowing heads) and chainsaw crews to clear dense thickets of Russian olive trees that had established below a mature cottonwood gallery forest (*Populus deltoides*, ssp. *wislizeni*) near Bernalillo, New Mexico. Russian olive trees felled by chainsaw crews received a cut-stump application of triclopyr (ester formulation, 50% solution) within five minutes of cutting. Treated stumps ranged in size between approximately 10 to 90 cm (around 4 to 36 inches). All cutting and masticating treatments were done in the winter.

The effectiveness of early and late summer herbicide treatments on the Russian olive root-sprouts, using four different herbicide formulations: glyphosate (5%), imazapyr (1%), metsulfuron (1 gm product/gal water), and the amine formulation of triclopyr (25%). All four herbicide formulations were mixed with water and a 0.25% nonionic surfactant. Russian olive root-sprouts were counted during spraying and averaged about 150 per plot. Counts of live versus dead root-sprouts were made prior to treatment, and at the beginning (May) and end (September) of the following summer to determine plant control.

By early summer (around four months after clearing), root-sprouts of Russian olive were found throughout the treatment area. Study results indicate that glyphosate, triclopyr, and imazapyr were highly effective in controlling Russian olive root-sprouts, although treatment timing appeared to influence effectiveness. For example, imazapyr effectively controlled Russian olive sprouts when applied in August (88%), but control was poor when applied in June (40%). Conversely, triclopyr gave better control of Russian olive root-sprouts when applied in June (91%) than August (78%). Glyphosate provided high root-sprout control following both June (91%) and August (93%) treatments. Metsulfuron showed equivalent control on both spray dates (75%), but the rate we applied was probably too low for effective plant control.

Caplan (2020) followed up the initial evaluation study with additional work that involved an early summer (June 15–July 15) foliar application of 25% triclopyr (amine) formulation to Russian olive root-sprouts for three seasons following mechanical clearing. Although not quantified, root-sprouts by the end of the third summer were less than three per acre.

Take-home management information if Russian olive becomes a problem in the Horseshoe Reservoir study area, include:
- Treating cut stumps that are less than 20 cm (around 8 inches) in diameter with herbicide resulted in far fewer root-sprouts compared to stumps that were not treated.
- Early summer foliar herbicide applications to Russian olive root-sprouts using triclopyr (25%) produced high mortality (>90%) after one year. Treating with glyphosate herbicide (5%) can provide similar levels of control following early or late summer foliar treatments.
- Root-sprouts from Russian olive trees with basal stem diameters greater than 20 cm may be more effectively controlled (with fewer herbicide applications) if the tree is first uprooted to remove the stump and the larger attached roots.

- Although high rates of mortality can be achieved with one herbicide treatment following mechanical clearing, treating re-sprouts with herbicide for three summer seasons to achieve nearly 100% control.

SALT CEDAR OR TAMARISK (*Tamarix* spp.)

Saltcedar (*T. ramosissima*, *T. chinensis*, others) is an invasive species native to Eurasia that has proliferated across over 1.5 million hectares of riparian habitat in the United States (Sher and Quigley 2013). Of the eight or so tamarisk species (*Tamarix* spp.) introduced to North America, some of the most common and problematic species naturalized across the southwestern U.S. and northern Mexico are *T. ramosissima*, *T. chinensis* (some authorities consider *T. ramosissima* synonymous with *T. chinensis*, *T. pentandra* and *T. gallica*), and *T. aphylla*. *T. ramosissima* and *T. chinensis* are deciduous species native to China, although the former has a distribution extending into the Middle East. Both species have similar structure, can form dense thickets, and are known to hybridize. For the purposes of this review, we combine and use the common name saltcedar or tamarisk to refer to these two species. *T. aphylla* is a larger evergreen native to Eurasia (can grow over 18 meters tall [60 feet]), and can easily be distinguished by its smoother, pine-like needles. We refer to this species as the Athel tree and simply use the term tamarisk when discussing information relevant to all three species.

Tamarisk was introduced to the western U.S. as an ornamental plant and also was widely used as a shade tree or windbreak and to stabilize eroded banks. It quickly escaped cultivation and currently is naturalized along most river systems in the southwestern U.S. and northern Mexico. Tamarisk has become the third-most common tree along rivers in the western U.S., occupying an estimated 1.5 million hectares (around 3.7 million acres) (Tamarisk Coalition 2017; Friedman et al. 2005). It also was introduced to Australia in the 1930s and, as in North America, has become a serious environmental issue there. The distribution of tamarisk ranges from below sea level to 2,400 meters (roughly 8,000 ft), but it is particularly problematic at lower elevations where it sometimes forms monocultural thickets (Zavaleta 2000).

Native riparian trees such as cottonwoods can outcompete tamarisk when water is sufficient and soil chemistry is within tolerable levels (Bunting et al. 2011; Sher and Marshall 2003; Sher et al. 2002). Shading or crowding by other plants such as cottonwood can also hinder tamarisk growth (Bunting et al. 2011). However, research over the past couple of decades indicates that tamarisk inhabits a broader environmental niche leading to the displacement of cottonwoods and willows in areas where these native plants are no longer adapted to the conditions imposed by river management (DiTomaso 1998; Taylor and McDaniel 2004; Nagler and Glenn 2013a; Anderson 1995). Once tamarisk is established in significant numbers it is difficult to control and almost impossible to eradicate completely (Pearce and Smith 2003). Physiological adaptations that have allowed tamarisk to proliferate along human-altered drainages, floodplains, and riverbanks include: 1) high, year-round seed production with distribution by wind and water; 2) rapid germination and seedling establishment across a broad range of environmental conditions (Brotherson and Winkel 1986); 3) extreme tolerance to high salinity and low soil moisture (Glenn and Nagler 2005); and 4) the ability to resprout after stems are cut to ground surface, following burning, or from severed stems (DiTomaso 1998). Tamarisk tends to proliferate when riparian conditions are open with little overstory, and where its root systems are able to access saturated soils. As a facultative species, tamarisk can establish off-channel on disconnected

floodplains, but also thrives in-channel where it can stabilize active channel bars, promote sediment deposition, and prevent bank erosion and widening of channels during flood events (Keller et al. 2014, Dean and Schmidt 2011). These changes in geomorphology have contributed to the channelization of once dynamic systems (Birken and Cooper 2006). Native species that historically required flooding and associated fluvial processes for natural recruitment are not adapted to these changing environments.

Management

Decades of research, field trials, and management have provided numerous resources to help understand when, where, why, and how to manage tamarisk (see, for example, Anderson et al. 2004; Sher and Quigley 2013; Bunting et al. 2020a). Commonly cited objectives associated with tamarisk management include: 1) augmenting streamflow, based on the assumption that tamarisk consumes large amounts of water (Bay 2013; Di Tomaso 1998); 2) protecting and enhancing cottonwood/willow communities where tamarisk has established (Barrows 1998); 3) improving wildlife habitat (Engel-Wilson and Ohmart 1978; Ellis 1995; Bailey et al. 2001); and 4) decreasing riparian forest fire frequency and severity (Shafroth et al. 2005). Researchers continue to evaluate the amount of water (particularly streamflow) that may be saved by controlling tamarisk. Water consumption in tamarisk, like native cottonwoods and willows, has been correlated to leaf area and is highly variable as it is influenced by a host of environmental factors (Nagler and Glenn 2013a; Cleverly 2013). Some control efforts have quantified immediate water savings (Hatler and Hart 2011; Doody et al. 2011), but long-term impacts to streamflow are dependent on several factors, including whether water used by tamarisk was directly connected to the river (or residual waters associated with floodplain surfaces) as well as how vegetation establishment following treatment impacts the water balance. While salvaged water may contribute to aquifer recharge or may increase water availability in floodplain soils, one should not count on a dramatic and long-term increase in streamflow (Sheng et al. 2014).

Tamarisk-control efforts should be evaluated on a site-by-site basis to weigh the benefits and disadvantages that may result from the specific actions proposed. If establishing native species is improbable due to site constraints (such as low water availability, lack of flooding, high salinity, or an absence of source trees), the value of controlling tamarisk should be questioned as it may result in an overall decrease in available habitat for native wildlife species, underscoring the importance of accompanying tamarisk management actions with native plant revegetation (Briggs 1996; Glenn and Nagler 2005; González et al. 2017a; González et al. 2017b; Bunting et al. 2020a). Such could be the case in Horseshoe Reservoir if upon further evaluation some of the Horseshoe Reservoir restoration sites proposed in this report prove to be unsuitable for native habitat,

Another factor that complicates the question of whether or not to control tamarisk is that tamarisk species provide habitat for several native species. In fact, riparian habitat can still be considered high quality even if tamarisk becomes a dominant part of a mixed plant community that includes native species (Sogge 2008; van Riper et al. 2008). Researchers have found that habitat value for many native species does not significantly decrease until tamarisk achieves 90 percent cover, and some estimates indicate a native tree composition of 10 to 40 percent provides optimal habitat (Cohn 2005; Sogge et al. 2008 van Riper et al. 2008).

For Horseshoe Reservoir, the decision to embark on a concerted tamarisk management program can be even further complicated as it provides habitat for the endangered southwestern willow flycatcher. The southwestern willow flycatcher now breeds in tamarisk throughout much of its range, as the invasive tree has similar characteristics to the bird's native habitats, including a dense structure, high canopy cover, tall stature, and mesic or wetland habitat (Sogge et al. 2008). It is generally accepted that the bird will select tamarisk when native species are not present or do not meet structural requirements for successful nesting.

Control Methods

A variety of methods have been used over the years to control tamarisk. Equipment availability, financial constraints, available personnel, time needed to complete the task, environmental restrictions, biological limitations, and numerous other factors enter into the decision-making process when selecting a control procedure (McDaniel and Duncan 2000). Methods summarized below for tamarisk control can be used alone or in combination depending on the restoration objective and characteristics of the site.

Manual

Manual control consists of the use of hand tools (shovels, hoes, pick axes, etc.) to remove plants. Typically, manual control is only effective during the seedling stage when the entire plant with root can be pulled out of the ground. While this method is not used for large-scale control of tamarisk, it can be effective during post-project maintenance when seedlings begin to germinate (USDA 2010).

Mechanical

Mechanical control includes the use of mechanized tools to cut or remove stems or entire trees. Chainsaws are often used to cut stems or trees just above ground level and heavy machinery equipped with implements can mow, rip, disk, or root-plow portions of or the entire plant. Bulldozers with a front-mounted dirt blade are commonly used to remove above-ground biomass (using a front-mounted dirt blade), to clear large fields (with a front-mounted rake), and to pile brush (using a hydraulic thumb or articulating loader). Root-plowing, however, is the most effective mechanical technique for controlling tamarisk because root plows target roots 30 cm (about 1 foot) or more below the ground surface (Di Tomaso et al. 2013). In fact, grubbing (i.e., digging up the root or plowing to uproot plant materials) is the only effective mechanical method due to the ability of tamarisk to resprout. Disadvantages of mechanical methods include disturbance of surface soils leading to wind and soil erosion and the production of tamarisk fragments that can resprout adventitiously (Di Tomaso et al. 2013). A synopsis of several restoration projects also showed that high-disturbance techniques, such as mechanical removal or fire, result in the highest abundance of noxious weeds compared to other techniques (Gonzáles et al. 2017a). Therefore, it is cautioned that restoration planning should discuss potential implications that mechanical treatments alone may have on weedy plant succession. Follow-up maintenance with selective grubbing or a spot herbicide will often improve effectiveness and supplemental seeding or planting with native species can further increase diversity.

Prescribed Burning

Conducting a prescribed fire—a planned, controlled burn conducted to meet specific management objectives—can effectively reduce the above-ground live biomass, potentially

facilitating and improving the effectiveness of follow-up treatments. It is important to emphasize that although burning tamarisk can kill it outright (when the burn is sufficiently hot and the trees are already stressed by environmental conditions), burning alone without follow-up management is often not effective, as it often promotes resprouting and flowering (Di Tomaso et al. 2013). Strategic cutting and placement of tamarisk branches and other woody debris can also increase fuel loads, promote fire propagation, and increase fire severity (Hohlt et al. 2002). Regardless, conducting prescribed fire followed by selective herbicide treatments (Di Tomaso et al. 2013) or follow-up mechanical control strategies such as grubbing or root-plowing (Barranco 2001) appears to be most effective. As noted above, high-disturbance control techniques, such as fire, can induce secondary invasions of non-target invaders (Gonzáles et al. 2017b). Typically, use of prescribed burning would be followed by active revegetation and maintenance of undesired species. Planting or seeding a cover or nurse crop (e.g., early successional herbaceous plant or subshrub) alongside targeted riparian shrubs and trees is another technique used to suppress undesired, weedy non-natives (Eubanks 2004). In particular when intense fires result in burning to mineral soil, cover crops will limit erosion and rebuild soils by increasing soil organic matter and essential nutrients (Jones 2016).

Chemical
Chemical control methods include the application of herbicides. No matter what herbicide or application method is used for tamarisk control, resprouting is to be expected, which often necessitates follow-up treatment. An evolution of herbicide trials and the banning of some chemicals by federal agencies has narrowed the list of effective herbicides to a common few: triclopyr as a bark penetrant (Neill 1988), imazapyr for foliar application (Taylor 1987), and glyphosate, which is typically used for broadleaf plants and grasses as it is absorbed through foliage and minimally through roots (Table 2).

Basal-bark application and cut-stump methods are often used when tamarisk is intermixed with native plants, or when the control program implements selective control. The basal-bark treatment involves applying an herbicide mixture (such as triclopyr) to the lower 45 cm (18 inches) of younger plants with a basal diameter of less than 10 cm (four inches). Basal-bark treatments are not as effective on older trees with thick, furrowed bark (USDA 2010). The cut-stump method involves a combination of removing as much of the above-ground biomass as possible (usually with a chainsaw) followed immediately by the application of an effective herbicide directly on the cut stump. Stumps with less than a 10-cm diameter should be thoroughly wetted to kill roots, while stumps greater than 10 cm should ensure herbicide application of the cambial layer (the growing part of the trunk) (USDA 2010). Foliar treatments should be made in late summer or early fall when plants are preparing to shut down for the winter season and translocating carbohydrates to the below-ground tissues (Di Tomaso et al. 2013). Cut-stump treatments can be made year-round, but will not be effective during droughts, since the method relies on the herbicide to be drawn into the plant tissue. In addition, glyphosate applications are more lethal to tamarisk after recent rains have removed the buildup of salt from leaf excretions, which can otherwise reduce herbicide absorption (Di Tomaso et al. 2013).

TREE OF HEAVEN (*Ailanthus altissima*)
Background
Much of the below is summarized from an excellent publication by US Forest Service that
provides background, distribution and management options for Tree-of-heaven (US Forest
Service 2014). Tree-of-heaven is a fast growing tree that was introduced as an ornamental into
the United States from China. The tree goes by a variety of other common names, including
ailanthus, Chinese sumac, stinking sumac, paradise tree, copal tree, Brooklyn palm. The 'tree-of-
heaven' moniker comes from its tall height (60 to 80 feet). The tree produces clusters of small,
yellow-green flowers mostly in June and July. It is dioecious with female trees producing
clusters of persistent, one-seeded, winged fruit that are similar in appearance to those found on
maples. Male trees produce groups of staminate flowers that smell like burned peanuts or
cashews. Like saltcedar, tree-of-heaven is a prolific seed producer, producing up to 300,000
seeds per tree in a year (US Forest Service 2014).

The central reason why tree-of-heaven is included in this 'top four' list is that it is extremely
competitive and fast-growing. Young sprouts grow as much as 3 m to 4.5 m (10 to 15 feet) a
year and, once established, one tree can rapidly develop into thickets via root sprouting that can
overrun native vegetation. For this reason, this species may be a good 'nip-in-the-bud' candidate
with management approach focused on routine monitoring and targeted elimination of *Alianthus*
if found.

Control Methods
US Forest Service (2014) reviews a variety of practical techniques for controlling the spread of
tree-of-heaven. These techniques include: (i) cutting trees before they become too large; (ii)
cutting trees in early summer when root reserves are lowest; (iii) cutting regrowth repeatedly and
frequently, and applying herbicide to cut surfaces; and (iv) providing shade from competitive
native plants after control efforts. Recommended herbicide applications include foliar spraying,
cut stump and basal stem application (e.g., hack and squirt techniques) with herbicides that have
glyphosate, imazapyr, triclophyr, amongst others, as the main active ingredient.